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PHYSIOLOGY.

A MANUAL FOR STUDENTS AND PRACTITIONERS.

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ILLUSTRATED WITH ONE HUNDRED AND FIFTY-THREE ENGRAVINGS.

LEA BROTHERS & CO.,
PHILADELPHIA AND NEW YORK.

WESTCOTT & THOMSON,
ELECTROTYPERS, PHILADA.

PREFACE.

In preparing the present volume the authors make no claim to original research. Their purpose is, frankly, not only to help the student acquire a knowledge of physiology such as will enable him to read with better understanding the larger works on the subject; but also to give him actually fuller and more accurate information than can be obtained from the various and popular quiz-compends.

Thus, in each section, in addition to the purely physiological aspects, histological considerations are discussed, such as those of the *cell* in general and of the *neuron* in the nervous system; and, wherever practicable, the application of physiological principles to pathological conditions is also dealt with.

Acknowledgment as to source of material is made to the larger works of Chapman, Kirke, and Foster, to the manual by Dr. F. A. Manning, and to the lectures delivered at the College of Physicians and Surgeons of New York.

HOWARD D. COLLINS,
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CONTENTS.

PHYSIOLOGY.

GENERAL CONSIDERATIONS.

Physiology, from the Greek *φυσις* and *λογος*, literally means a discourse on nature. At present, however, the word has a more limited significance, meaning that branch of science which treats of the workings of the healthy living body.

That portion of physiology discussed in the following pages is the physiology of the healthy living *human being*. From the very nature of things it is evident that every detail of physiology cannot be studied on the human subject, and the deficiency has been supplied by analogous study on the lower animals. In order properly to understand physiology, it is essential that the student be somewhat familiar with anatomy, or that branch of science which teaches the gross structure of the body. To appreciate the workings of a machine, at least a superficial knowledge of its component parts is necessary.

Life: Our definition of physiology assumes the body to be alive; but what *life* is, is a very difficult subject to explain. It may be described as the stimulus which keeps active the functions of the body, the characteristic phenomena exhibited by living beings. It is really indefinable; for while it is readily possible to state the differences between living and dead things, it is impossible to define these differences.

Living body compared to a machine: The living body may be compared to any piece of complex machinery, the parts being carefully adjusted to one another and performing their work as long as the proper stimulus is applied. When the stimulus fails—and in the case of animals and plants the stimulus is called *life*—the machine stops.

Still another comparison may be drawn between the body and a piece of machinery—say, a steam engine. There is for both the need of fuel that can be oxidized by burning, and of resultant energy, liberated in the form of heat and visible motion. Also, as the parts are subject to wear and tear, new parts must be supplied. In the case of a steam engine, the fuel is the coal fed to the boiler and oxidized by burning. In man the fuel is the food we eat, burned up in the presence of the oxygen we breathe. But here the analogy ceases, for whereas the coal supplied to a steam boiler never forms an integral part of the boiler, in man the food-stuffs are absorbed and go to form part of the individual himself before they are broken down by the oxidizing agent.

Metabolism: The process of building up the food-stuffs, already properly digested, into a part of the body is called *anabolism*. The breaking down is the *katabolic* process, or katabolism. Both together are called *metabolism*.

To make the **simile** between man and a steam boiler perfect, we should have to imagine a boiler made of coal, instead of iron, which being ignited on its inner surface generated heat which caused the contained water to boil. And further, we should have to imagine that as fast as the inner layers of coal were consumed fresh coal was placed on the outside to make up for the loss.

Thus we see that food is digested, absorbed, and incorporated into the body, only to be broken down again by *oxidation*.

This **oxidation**, or burning, is the source of the *energy* of the body, manifested as *heat* and *visible motion;* and also of certain *waste-products*, comparable to the smoke and noxious gases of a steam boiler.

These waste-products are **eliminated** by the body through four great channels—the breath, sweat, urine, and fæces.

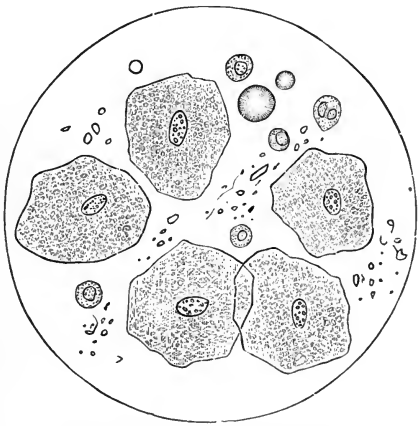
CELLS.

General structure: The fundamental element or unit of structure of all living bodies is the *cell*. Some bodies, for example the amœbæ, are so small and so simple in structure as to consist of only a single cell. On the other hand, the

higher animals have millions of cells, highly differentiated for the different functions they are called upon to perform. Let us examine a cell, and see what it looks like and of what it consists.

A cell (Fig. 1) is a mass of living matter, known as *protoplasm*, varying from $\frac{1}{5000}$th to $\frac{1}{120}$th of an inch in diameter, which may or may not have a limiting membrane or capsule. As a general rule, animal cells do not have a capsule, while vegetable cells usually do. The contents of the cells may be liquid, semi-liquid, or granular in character. The granules

Fig. 1.



Buccal and glandular epithelium.

in some cells, according to many histologists, are united by filaments, the cell-contents consisting then of a network.

The nucleus: Usually amidst the cell-contents may be seen a still smaller cell, the nucleus; and within this the *nucleolus*. Though in some kinds of cells no nucleus can be found, it may be assumed as true that at some period of its life every cell had one, though it may have been lost in the course of development.

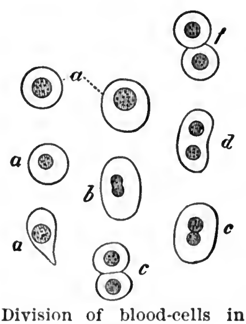
Essential features of a cell: Great difference still prevails among histologists as to the relative importance of the nucleus

and nucleolus; of the cell-contents and cell-wall. Some hold that the nucleus is the all-important element in cell-life; others maintain that the cell-contents hold this position. As yet their relative significance is not definitely understood.

Importance of the cell: Though there is some doubt as to the exact use of the different parts of the cell, no doubt exists that the life of the organism resides in the cells composing it. Among reasons for this belief may be mentioned the fact that the life of human beings begins as the *ovum*, a cell; and that the tissues of the embryo consist of modified cells, the lineal descendants of this primitive cell or ovum.

Cells—gemmation: If one watches the career of a cell, it will be seen to give out a little bud or sprout from one side; this bud or sprout grows in size, and the band connecting it with the original mass becomes more and more constricted until the offshoot is separated from the parent-mass. Thus a new cell is born, and after its full growth is attained it shows all the characteristics of the parent-cell. Such a process of birth is called "gemmation" (Fig. 2).

Fig. 2.

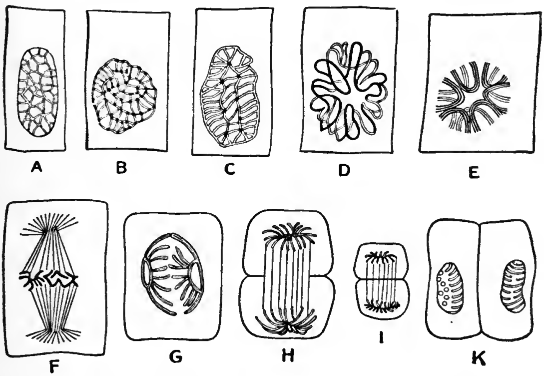


Division of blood-cells in embryo of stag (Frey).

Karyokinesis: This (Fig. 3) is the *indirect* or *mitotic* division of the nucleus, hence also called *karyomitosis.* The *cell-nucleus* is enlarged, and its net-like arrangement disappears and is changed into a *skein of filaments* of chromoplasm, into which the *nucleoli* are merged (convolution). Now appears another *set of filaments*, arranged like a *spindle*, which grows until equal to the diameter of the nucleus. By this time the filaments of the first-named *skein of filaments* have become shorter and V-shaped, and *radiate* from the equator of the spindle (aster stage). Then each chromoplasmic filament splits longitudinally into two others, and separation, beginning at the V, is soon distinct. The *apices* of all these loops of filaments now *swing away from* the equator of the spindle and *point toward* the poles of the spindle, so that their *ends* look toward the equator (diaster

stage). There are thus two groups of filaments, the apices of one pointing to one pole and those of the other group pointing to the opposite pole of the spindle. Each group becomes converted into a daughter-nucleus, and the process is completed by a complete constriction and division across the equator of

FIG. 3.



Karyokinesis. A, ordinary nucleus or a columnar epithelial cell; B, C, the same nucleus in the stage of convolution; D, the wreath or rosette form; E, the aster or single star; F, a nuclear spindle from Descemet's endothelium of the frog's cornea; G, H, I, diaster; K, two daughter-nuclei (Klein).

the spindle, two nuclei being thus produced, as the cell-protoplasm soon divides also.

Development of cells: The daughter-cells, whether produced by the direct or the indirect form of cell-division, grow until they reach maturity. They then in turn subdivide and give origin to more cells. Thus it will be seen that every cell owes its origin to some preëxisting cell.

As to the question of the origin of the original parent-cell of all living matter, we have no answer. The whole process of cell-division and cell-structure is far more complex than has been given above; and for further details the student is referred to more exhaustive works on the subject.

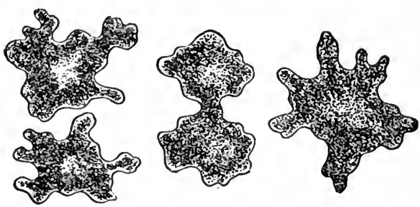
Decay and death of cells: The comparatively brief life of cells is brought to an end either through *mechanical abrasion* or by *chemical transformation.* Epithelial cells give frequent

examples of the former method. As the cell approaches the surface it becomes more and more flattened and scaly, till at last it is simply rubbed off. Hence epithelial cells are found in the mucus of the mouth, intestine, etc. In the case of chemical transformation the cell degenerates in various ways, the process being frequently normal, though it may be pathological. Thus fatty degeneration of the cells in the breast produces the oil-globules in the secretion of milk.

The **protoplasm** of which all cells are made up has been called the basis of life. Protoplasm is an unstable albuminoid substance of more or less gelatinous consistency. Its reactions are those of albumin (coagulation by heat and mineral acids), and its chemical composition is in varying proportions of the elements C, H, O, N, and S. Protoplasm is living albumin, or proteid. Besides proteid, every cell contains water.

The **amœba** is a microscopic animal that consists of but one cell; yet this one cell performs all the animal functions.

FIG. 4.



Protamœba (Hæckel).

(1) It is *capable of motion* (Fig. 4), the cell sending out a small branch or arm of the protoplasm. This branch, or *pseudopod* as it is called, attaches itself to some part of the environment, and then the rest of the cell is drawn forward until the whole cell seems to flow to and into its branch. The process is then repeated, the cell advancing steadily forward.

(2) It has the *power of food-absorption;* the cell flowing around and completely enveloping any particle of food it may meet. Later on, such of the food as has not been absorbed is excreted, by a process of flowing away, on the part of the protoplasm.

(3) It also *absorbs oxygen* from the surrounding atmosphere.

(4) It is *irritable to stimuli;* and is capable of (5) *reproduction* and (6) *growth.*

Thus we see that the amœba presents in its single cell all the main functions of the higher animals. But the individual cells of the human body are by no means so well endowed with functions as the amœba.

Differences between plants and animals: The most essential difference lies in the fact that vegetable protoplasm can build up new albuminous compounds out of such chemical bodies as water, carbonic acid gas, and inorganic mineral salts. Animal protoplasm, on the other hand, must have ready-formed albuminous food in order to live. Vegetables exhale oxygen, but inhale carbonic acid gas; while animals do the reverse.

Specialization of cells: As a rule the body-cells are highly *specialized* for the fulfilment of one or more functions, *to the exclusion of all others.* Where we find two or more cells of the same *kind* aggregated together, the mass is called a *tissue.*

Two or more tissues of different kinds are spoken of as *organs.*

By *apparatus* is meant an association of organs for the performance of a common function. Thus the stomach, intestines, and pancreas may be spoken of as a collection of organs, forming an apparatus for the common function of digestion.

In ordinary parlance an organ is "the instrument of function, the performer of a function."

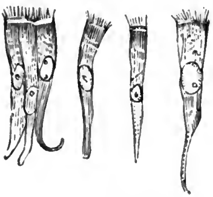
Classification of tissues: The cells in man are, roughly speaking, found to make four main classes of tissues: epithelial, connective-tissue, blood-cells, and nerve-cells.

Epithelium: The name "epithelium" is given to the cells which cover the skin, and the mucous and serous membranes of the body; and which also enter into the formation of the glands. Its varieties are—(1) *simple,* a layer of flat (squamous), cubical (spheroidal), or cylindrical (columnar) cells, as in the serous and mucous surfaces; (2) *stratified,* when it occurs in layers, as in the skin; (3) *transitional,* where it has the characteristics of both in situations where the other two

forms approach one another, as in the bladder. (4) In the glands are found *functional cells*, which partake of the character of the epithelium of the surface. They are arranged in groups about the ducts. Such cells are often known as secreting or glandular epithelial cells.

Simple epithelium possesses hair-like processes in certain locations, and this is known as *ciliated epithelium* (Fig. 5). The hairs are endowed with motion, and wave in such a manner as to throw forward small particles which fall upon them.

Fig. 5.



Columnar ciliated epithelium-cells, from the human nasal membrane; magnified 300 diameters (Quain and Sharpey).

The principal uses of epithelium are: *protection*, as skin, serous surfaces; *motion*, ciliated epithelium of air-passages and Fallopian tubes; *secretion*, in glands—*e. g.*, gastric juice; *sensation*, in the cones of the retina, olfactory cells of the nose, etc.

Endothelium is a simple form of squamous or scale-like, flat epithelial cells which line the serous membranes and the bloodvessels. The cells are very delicate, and are not stratified. They are of various forms, usually irregularly polygonal, and are joined at the edges so as to form a sort of mosaic.

Connective tissues form the frame and supports of the body and of the organs of the body. The ligaments, tendons, fasciæ, cartilages, and bones are examples of them. The fibrous connective-tissue cells are found in all organs in greater or less amount. In the organs whose use is the support of the body or one of its members these cells predominate. In other organs the fibrous cells serve to hold in place the functional cells and to maintain the shape of the organs.

CHEMISTRY OF THE BODY.

The **ultimate analysis** of the human body shows it to consist of the following elements: carbon, hydrogen, oxygen, nitrogen, magnesium, calcium, sodium, potassium, sulphur, phosphorus, manganese, silica, iron, chlorine, fluorine, and

iodine. Of these, only oxygen and nitrogen are found free, the other elements existing as compounds.

By **proximate principles** we mean those elements or compounds that exist as such in the body. Thus sodium chloride is a proximate principle, as it is found as such in the human body. Neither the metal sodium nor the gas chlorine, however, can be considered as belonging to this class, as they do not exist or act as such in the body. The proximate principles are subdivided into two great classes—*organic* and *inorganic.* It will be wise to attempt at this point to draw a clear distinction between organic and inorganic substances.

Organic substances are nearly always highly complex bodies containing many elements. Two particular elements—*carbon* and *hydrogen*—enter into all organic bodies. Some organic substances are very simple chemically and may contain no elements except carbon and hydrogen. It was formerly supposed that any substance must, in order to be included in this class, have been at some time either an intimate part of, or a product of the activity of, a living body; or else either an intimate part of, or a product of the decomposition of, a body that had lived. Of recent years, however, many of these principles have been prepared in the laboratory from inorganic elements without invoking the aid of a so-called "vital force"; and there is every reason to suppose that in time all will be. Such being the case, the distinction between organic and inorganic substances regarded at one time as being so essential, is without philosophical significance, and is only made use of as a matter of convenience. Organic substances are further subdivided into those containing *nitrogen* and those not containing it.

Inorganic substances are best defined by negativing the above conditions—that is to say, if a chemical body fails to fulfil every condition given above, it cannot be classed as "organic," but is "inorganic." Carbon dioxide (CO_2) is a body that fulfils all the conditions for being organic to a marked degree, except that there is no hydrogen present; hence breaking the rule that both carbon and hydrogen must be present in order that a body be organic. Nevertheless carbon

dioxide is the one exception allowed, and is classed among both organic and inorganic substances.

With few exceptions the inorganic principles are so firmly combined with the organic that, as the latter become effete and are eliminated, the inorganic substances are cast out with them. Some of them play a more important *rôle* than others and are found in greater quantities.

List of inorganic proximate principles: The inorganic principles found in the human body are: oxygen; nitrogen; water; hydrochloric acid; chlorides of sodium and potassium; sulphates of sodium and potassium; carbonates of sodium, potassium, calcium, and magnesium; phosphates of sodium, potassium, calcium, and magnesium; also small amounts of compounds containing iron, silica, fluorine, iodine, and manganese. To complete the list we must add carbon dioxide.

Uses of inorganic proximate principles: The uses to which these principles are put by the body are not well understood; but they are necessary in making the structure of the body or in aiding chemical work. They are not sources of chemical potential energy. Many of the inorganic proximate principles are taken into the body and excreted unchanged. Others not only are taken into the body, but are also manufactured in the body as the result of oxidation and breaking up of more complex organic bodies. As a result of this manufacture we should expect to find that certain of the inorganic proximate principles are excreted in greater amounts than they are ingested. Such is proven to be the case, for water, and the sulphates, phosphates, and carbonates leave the body in greater amount than that in which they enter.

Distribution: The inorganic proximate principles are found distributed in various parts of the body. Water and sodium chloride are omnipresent. Oxygen and nitrogen are found in the blood and tissues. Potassium chloride is found generally, but not so omnipresent as the chloride of sodium. The phosphates and the carbonates of the alkaline metals are found in the blood, rendering the latter alkaline. The phosphates and carbonates of the alkaline earths are neutral, and give rigidity to the bones. Hydrochloric acid is present in the gastric juice. The less important salts are found elsewhere, and

play but an insignificant part. Water constitutes more than two-thirds of the weight of the body.

Organic proximate principles are divided into two great classes: (1) *nitrogenous* and (2) *non-nitrogenous.*

(1) The former take the principal part in the formation of the solid constituents of the body, and occur in all the body-tissues and -fluids. They make up the protoplasm of cells and essential ingredients of the fluids, both circulatory and excretory. Chemically, they are compounds of C, H, O, N, sometimes with sulphur or phosphorus. These, with few exceptions, are not crystallizable.

(2) The latter (non-nitrogenous) class of bodies are made up of the fats and carbohydrates. With the exception of starch, all of this class are crystallizable.

In striking contrast with the inorganic proximate principles, none of those belonging to the organic division, with the exception of butter and sugar of milk among the non-nitrogenous; and of casein of milk, mucus, epithelium, and epidermis, among the nitrogenous principles, ever appear among the excretions or secretions of the healthy human body.

Uses of organic proximate principles: All our vital manifestations depend on the energy derived from the organic matter of the body. This organic matter is constantly being used up, and to supply its place the body must acquire fresh organic matter. The essence of life is in change, and in this change the element nitrogen plays a very important part because of the readiness with which the nitrogenized proximate principles break down. This liability to breaking down is not only due to the presence of nitrogen, but also to the great number of molecules which all organic principles contain. Through this breaking down is derived the energy required for life.

Source of organic supply: Green plants have the power, by virtue of the *chlorophyl* in their substance, to convert the inorganic compounds, that are the food for plants, into simple organic bodies. Animals, on the other hand, cannot convert their inorganic foods into organic substances, but are compelled to eat organic bodies in order to have the necessary fuel on which they live. To illustrate: *green plants* live on water, nitrite and nitrate of potassium, sulphates of calcium

NITROGENOUS ORGANIC BODIES, OR PROXIMATE PRINCIPLES.

Proteids	1. Native albumins found in nature,	Egg-albumin, Serum-albumin,	Soluble in water and coagulable by heat.
	2. Globulins found in nature,	Globulin, Paraglobulin, Fibrinogen, Myosin, Vitellin, Globin,	Soluble in 1 per cent. NaCl sol.; coagulable by heat; nearly all precipitated by alcohol.
	3. Derived albumins, derived from Class 1 by action of acids, alkalies, or ferments.	Acid albumin, Alkali-albumin, Casein,	Soluble in weak (1 per cent.) HCl sol.; not coagulable by heat; precipitated by neutralizing solution.
	4. Fibrin, from Class 1 by action of "fibrin-ferment,"	Fibrin,	Insoluble in cold 1 per cent. HCl sol., but soluble at 60° C.
	5. Coagulated albumin, by heat, etc., from Class 1,	Coagulated albumins,	Soluble in gastric juice, becoming peptones; and also in strong acids, becoming acid albumin.
	6. Peptones, by action of digestive ferments on Class 1.	Peptones,	Very soluble in water; not precipitated by heat, acids, alkalies, or alcohol. Peculiar in dialyzing freely.
Gelatins	Gelatin, soluble in hot water.		
	Mucin, soluble in weak alkaline solutions.		
	Elastin, insoluble.		
	Chondrin, soluble in hot water.		
	Keratin, insoluble; probably a complex compound.		
Products of the decomposition of nitrogenous matter.	Crystallizable acids—*e. g.*, glycin, leucin, taurin, etc.		
	Urea and its allies—*e. g.*, kreatin, uric acid, xanthin, etc.		
	Pigments—*e. g.*, bile-pigments, melanin, hæmatin, etc.		
Nitrogenous, but of uncertain composition.	Ferments—*e. g.*, amylolytic, proteolytic, milk-curdling, etc.		

NON-NITROGENOUS ORGANIC BODIES, OR PROXIMATE PRINCIPLES.

Fats	Olein, liquid at ordinary temperatures.		United in fatty tissues.	Insoluble in water. Soluble in ether. " " chloroform. " " hot water. Saponify.
	Palmitin, solid " "	(melts at 113° F.		
	Stearin, " " "	(" 140° F.)		
	Cholesterin, chemically an alcohol, but closely allied to the fats.			
Carbohydrates	Starch, soluble in hot water, not in cold.	Not found in unchanged state in body, except as food.		Iodine-test (blue color).
	Glycogen, soluble in cold water.	In liver, by dehydration, glucose.		Iodine-test (red color).
	Dextrin, " " " "	Not found in body, except as food		All respond more or less readily to fermentation and copper-tests.
	Glucose, " " " "	Derived from saccharose and starch by ferment action.		
	Lactose, " " " "	Found in milk.		
	Maltose, " " " "	From starch by ferments, ptyalin.		
	Inosite, " " " "	Found in muscles and in heart.		Non-fermentable with yeast.
Fatty acids	Formic acid	Found only in perspiration.		
	Acetic "			
	Lactic "	" " " muscle-plasma.		

and magnesium, the phosphates of calcium, and some soluble salts of iron, all of which exist in the earth; also on the oxygen and carbon dioxide of the air. By various chemical combinations and changes these inorganic compounds are converted by the green plant under the influence of sunlight into simple organic substances.

Non-chlorophyl-bearing plants, such as fungi, have not the property of absorbing inorganic substances and converting them into organic substances, but must receive their food in the form of organic compounds; hence the fungi live on other plants. So too with animals; they must live on plants and other animals. From these plants and animals we eat we obtain, besides a number of inorganic salts, water, etc., the *three great classes of food-stuffs* which are eventually to be digested, altered, and assimilated into the body, then "burned" with the liberation of energy, and finally to be cast off as waste-products by means of the sweat, breath, urine, and fæces. These three classes of food-stuffs are *proteids, carbohydrates,* and *fats.* How these foods are absorbed and assimilated will be studied later in the chapter on *Digestion.* To be sources of energy, the tissues of the body must be oxidized; this is accomplished by the oxygen conveyed from the lungs to the tissues by the blood.

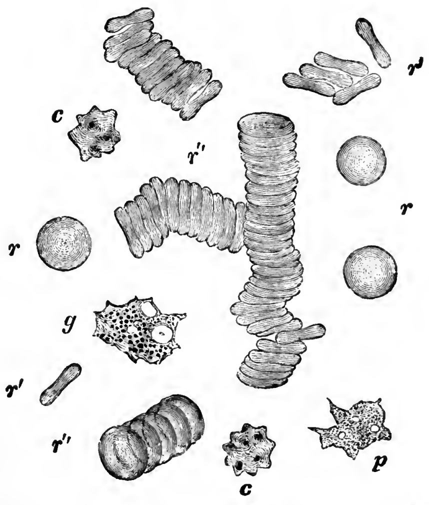
THE BLOOD.

General observations: Since the earliest times it has been recognized that the blood is the most important fluid in the human body; that it is, indeed, indispensable to life. Its loss prostrates and enfeebles the body. With excessive hemorrhage life itself ebbs away. This is readily evident when it is known that the blood, circulating through the system, carries to the tissues and the cells composing them material for their growth, renewal, and repair; and removes from them that which has become effete. It also tends to equalize more or less the temperature throughout the body.

Gross appearance: Freshly drawn blood is a somewhat viscid opaque fluid of a more or less pronounced red color. This color, which depends entirely on the amount of oxygen present in the blood, varies according as the blood is drawn

from the arterial or the venous system. That drawn from the arteries or pulmonary veins is of a bright scarlet, and contains a large amount of oxygen; while that from the systemic veins is bluish-red to reddish-black, and has far less oxygen. The opacity is due to the fact that blood is not a homogeneous liquid, but consists, as we shall see later, of two elements—corpuscles and plasma. These, differing in their refractive power, oppose the transmission of light, thus causing the opacity.

FIG. 6.



Human blood as seen on the warm stage. Magnified about 1000 diameters. *c*, *c*, crenated red corpuscles; *p*, a finely granular; *g*, a coarsely granular pale corpuscle; both exhibit two or three vacuoles. In *g* a nucleus also is visible. *r*, *r*, single red corpuscles, flat; *r′*, *r′*, the same on edge; *r″*, *r″*, the same in rouleaux (Quain).

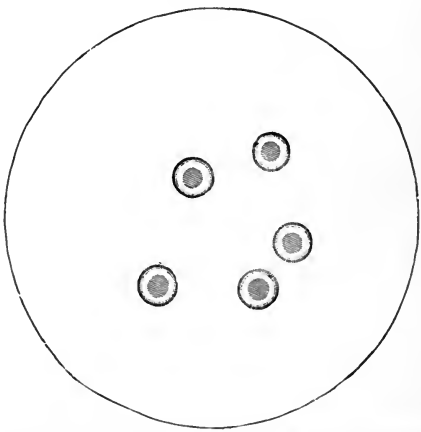
Physical characteristics: The *specific gravity* of the blood at ordinary temperature varies between 1045 and 1062. It is of a slightly *alkaline reaction*, due to the phosphates and carbonates of the alkaline metals, and has a *salty taste* and a *peculiar* characteristic *odor*. The degree of alkalinity, estimated as Na_2CO_3, corresponds in human blood to 0.35 per cent. of this salt.

If *examined under the microscope,* the blood will be seen to consist of a fluid, called *plasma* or *liquor sanguinis,* in which are suspended small particles called *blood-corpuscles.* The corpuscles are of three types, known as *red corpuscles, white corpuscles* or leukocytes, and blood-plates or *microcytes.*

The temperature of the blood in man is, on the average, 98.9° F.; but it is very probable that in certain parts of the body it is several degrees higher.

Quantity of blood: The total amount of blood is estimated as being one-thirteenth of the body-weight. Thus in an individual weighing one hundred and seventy pounds, the

FIG. 7.



Red globules of the blood, seen a little beyond the focus of the microscope (Dalton).

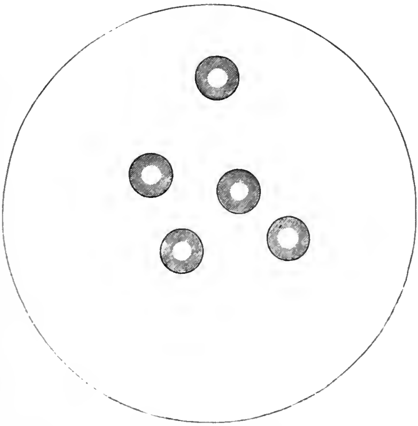
amount of blood in his body would weigh about thirteen pounds and would measure about six quarts. The corpuscles weigh about one-third of the total blood-weight.

Corpuscles: The corpuscles (Fig. 6) exist in large numbers in the blood, it being estimated that in every cubic millimetre of blood there are 10,000 leukocytes, 250,000 blood-plates, and 5,000,000 red corpuscles.

Red corpuscles: Human colored blood-corpuscles (Figs. 7 and 8) are circular, biconcave disks with rounded edges; in

diameter they are about $\frac{1}{3500}$th in.; in thickness about $\frac{1}{12000}$th in. In water they swell and become flat or convex. When seen singly they appear yellow, but their color is red when seen in groups. Microscopic examination shows that they have no nucleus and no limiting membrane; but they have an elastic framework, or stroma, which retains an individ-

FIG. 8.



Red globules of the blood, seen a little within the focus (Dalton).

uality for each corpuscle, and allows changes of shape to adapt them for capillary circulation, and brings them back to the original form after such distortion.

The *color* is due to a chemical body, called *hæmoglobin*, which is held within the stroma. The red corpuscles have a *specific gravity* of 1088, and are the heaviest of the component parts of the blood.

In all *mammals*, with the exception of the camel family, the *general character* of the corpuscles is the same as in man; but their *size* varies in the different animals (Fig. 9). The camel family have the same corpuscles as other mammals, except that the discs are oval instead of circular.

In *reptiles*, *fishes* (except a few species), and *birds* the red corpuscles are oval, nucleated, and usually larger than those of mammals.

Red corpuscles—origin : Like all the other cellular elements of the body, there must be a birth of new blood-cells to take

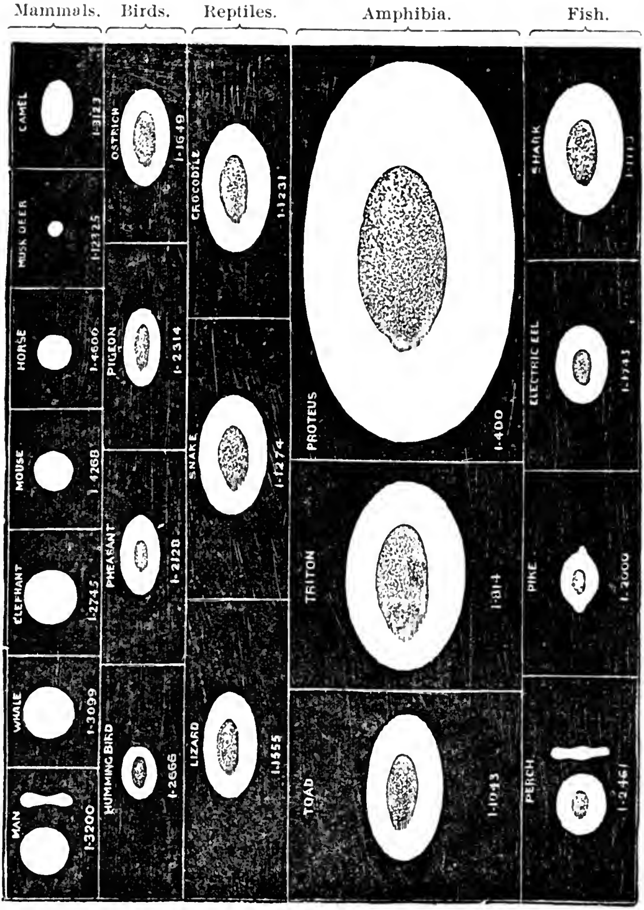


FIG. 9.

Typical character of red blood-cells of vertebrata (Kirkes).

the place of those whose life-work is done. The ancestors of the red blood-corpuscles are the large, irregular, polygo-

nal marrow-cells. These marrow-cells are found, as their name implies, in the marrow of the long bones. They are found in layers or phalanxes, each phalanx a little more highly developed than the layer underlying it. The most highly developed divide by karyokinesis, and are pushed off from the mass of cells by the growth of the cells below. The detached cells, after undergoing certain changes in shape, enter the blood-current and become the ordinary red blood-corpuscle. The marrow-cell is polygonal, nucleated, and only very slightly colored. To become a red blood-cell the marrow-cell loses its nucleus, assumes the biconcave disc-shape, and acquires a greater amount of coloring-matter, or hæmoglobin. Such changes have been observed to take place in the marrow-cells; and also in cases in which individuals have suffered severely from hemorrhage, during the recuperation, numbers of only partially transformed marrow-cells have been found circulating in the blood-current, not having had time to be fully altered, as the demand for new cells was so urgent.

What becomes of the nuclei which the marrow-cells cast off is not known. Suggestions have been made that these nuclei may become the blood-plates or else be destroyed by the leukocytes. These are merely suggestions, and not to be accepted as proven. Where the increase in coloring-matter which the marrow-cell acquires comes from, is also a source of speculation.

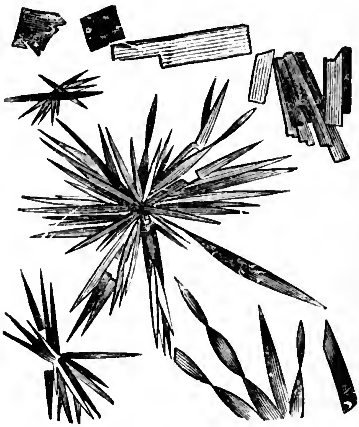
Red corpuscles—function: The one important and fundamental purpose of the red blood-corpuscles is *to convey oxygen* from the lungs to the tissues. As has been said, the red corpuscles consist of an elastic network or stroma, which holds, probably both mechanically and chemically, a highly complex proteid body called hæmoglobin, which, although crystallizable, is non-diffusible. The form of the crystals of hæmoglobin varies in different animals. In man they are prismatic, in the guinea-pig they are tetrahedral, in the squirrel they are hexagonal, and so on.

Hæmoglobin can be subdivided into two bodies—globulin (96 per cent.) and hæmatin (4 per cent.).

Hæmin (Fig. 10), the hydrochlorate of hæmatin, is formed

by adding muriatic acid to hæmoglobin. It is of especial interest from a medico-legal point of view, as it can be obtained, by proper manipulation, from a very minute quantity of blood. It forms characteristic crystals, rhombic

FIG. 10.



Rhombic crystals of hæmin, or hydrochlorate of hæmatin.

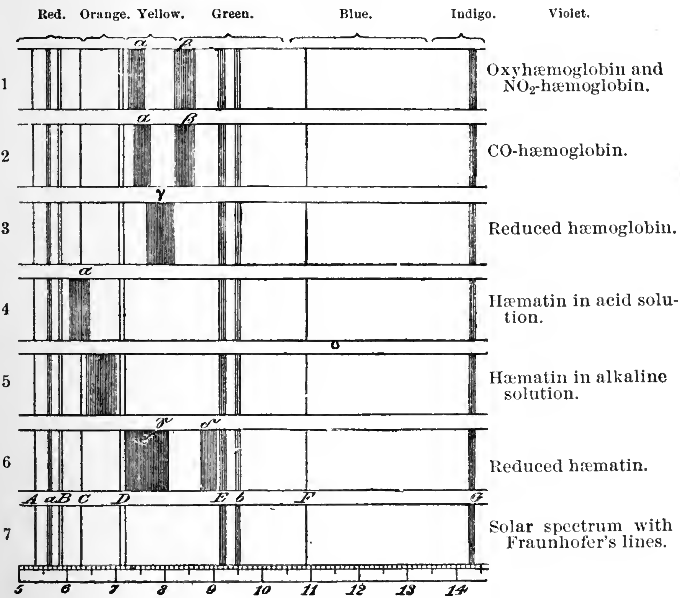
tablets, which are sometimes disposed as stars or crosses, of a red or brown color. If oxygen be added, the crystals assume a violet hue, while under the influence of carbon dioxide the crystals lose their transparency. Unfortunately, however, there is no characteristic form of these crystals for the different animals. We can prove that a certain material is or is not *blood*, but not that it is or is not *human blood*.

Globulin is composed of the elements C, H, N, O, and S. *Hæmatin* is composed of the elements C, H, N, O, and Fe. The *iron* is the important element; for the oxygen from the lungs forms a very loose chemical combination with the iron in the hæmoglobin.

When the red corpuscle rich in hæmoglobin reaches the lungs the oxygen absorbed from the air is rapidly taken up in loose chemical combination by the hæmoglobin. The corpuscle is now hurried with its load of oxygen to the dis-

tant tissues, where the oxygen is absorbed by the tissues, and the red corpuscle is carried back to the lungs for a fresh supply. Besides this, the red corpuscle has no other function except *diapedesis*—*i. e.*, a passive ability to pass through capillary walls. The student must bear in mind that the oxygen which enters into the chemical compound called

Fig. 11.



hæmoglobin (see formula above) is not the oxygen which unites with the iron, and which is taken into the hæmoglobin-molecule in the lungs, only to be given up in the tissues. The *first* "oxygen" spoken of is an essential of the hæmoglobin, and is retained as long as the molecule retains its chemical identity. Hæmoglobin rich with the *oxygen of respiration* is called *oxyhæmoglobin*. When this oxygen is entirely removed the proteid is called *reduced hæmoglobin*. Both reduced hæmoglobin and oxyhæmoglobin give perfectly

characteristic spectra (Fig. 11). This point has been of some value in medico-legal cases in determining the presence of blood in suspected stains.

Red corpuscles—death: After a period of functional activity the red blood-cell has outlived its utility and dies. Other red cells are lost from the circulation by hemorrhages of all kinds. These dead and lost red corpuscles are replaced by new cells from the bone-marrow, as has been already shown. Just what conditions determine the death of a red corpuscle, or just how the dead body is disposed of, is not accurately determined. The evidence points toward the assumption that the stroma of the corpuscle is chemically destroyed and absorbed by the tissues as proteid material. The hæmoglobin, after the destruction of the framework, is liberated and eventually eliminated as a part of the bile-pigment.

Leukocytes, or *white blood-corpuscles,* are spherical, granular masses of protoplasm, each having a nucleus, but no cell-walls. They are about $\frac{1}{2500}$th in. in diameter. Some appear to be much smaller, and probably this diminution in size is because these corpuscles have not yet attained full development. It has been said above that the leukocytes are spherical. This is true when the leukocytes are being carried along by the blood-current; but when the leukocytes exercise their power of locomotion, which permits them to emigrate (*emigration*) from the blood-current into the surrounding tissues, each leukocyte changes its shape and behaves in a manner identical with that of the amœba (Fig. 12). The properties and animal functions of leukocytes are the same as those of the amœba.

The white corpuscles differ in many respects, other than size and appearance, from the red ones. They are differently affected by the various reagents. They keep close to and even seem to adhere to the walls of the vessels in which they are circulating, while the red corpuscles keep in the middle of the stream. The white corpuscles are found in lymph, chyle, pus, and other fluids as well as in the blood; the more general name of leukocytes is often, therefore, given to them.

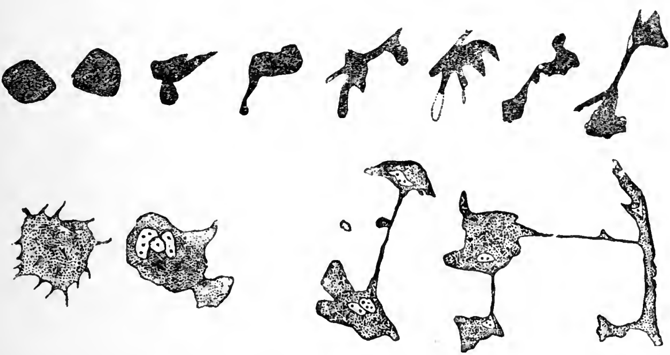
Leukocytes—varieties: Three varieties of leukocytes have been noted in the blood. The most marked physical difference is in the nuclei. The properties are the same, except in the amount of amœboid movement exhibited.

1. *Lymphocytes*, large single nucleus, very little cytoplasm, practically no amœboid movement. Most commonly found in the lymph.

2. *Mononuclear leukocytes*, large corpuscles with single nucleus, relatively small to size of the cell, free amœboid movement.

3. *Polynuclear leukocytes* are large corpuscles with a partially divided nucleus or even several distinct nuclei. The amœboid movement is particularly well marked.

FIG. 12.



Various forms assumed by the white corpuscles of the blood. The upper row represents the white corpuscles of man; the lower row, white corpuscles from the newt, showing changes effected in fifteen minutes (Carpenter).

Undoubtedly these three types are merely three stages in the development, the lymphocytes being the youngest.

Leukocytes—chemical composition: Leukocytes consist of water, inorganic salts (largely potassium salts), proteids, glycogen, nuclein, fat, lecithin, cerebrin, cholesterin.

Origin: The leukocyte owes its *origin* to the splitting up by karyokinesis of some previous leukocyte into two secondary cells. This birth takes place in most instances in the

lymphatic or adenoid tissue, and the new cells are poured into the blood-current by lymphatic channels.

Function: Leukocytes act as protecting agents for the body, by destroying bacteria that may get into the blood-current, lymph- or tissue-spaces into which the leukocyte can enter. The method of destroying the bacteria is supposed to be either by a process in which the leukocyte ingests the bacterium (*phagocytosis*), or else the leukocyte surrounds the bacterium with some substance that destroys it. The leukocytes act as agents in assisting the absorption of fats and peptones from the intestines.

Leukocytes are poured out in large numbers in any wound in the body, and by their presence act as barriers to infection. In such a wound some of the leukocytes may eventually become converted into granulation-tissue.

Among other uses, it has been suggested that leukocytes, when disintegrated, help keep up the necessary amount of proteid in the blood-plasma.

Death: The natural ending for the leukocyte is to be divided into two daughter-cells by karyokinesis. Other leukocytes are disintegrated in the blood-current. Again, other leukocytes are destroyed in the battle waged against bacteria. Others are lost by hemorrhage. Still others may be converted into granulation-tissue in wounds.

Blood-plates: The blood-plates, or *microcytes*, are small rounded masses of which little is known. They are much smaller than the red corpuscles. The blood-plates are supposed to assist in the coagulation of blood; but all we know at present is that the fibrin-fibrillæ seem to start from the microcytes. The microcytes may be the source of the fibrin, or may merely serve as mechanical anchors.

Blood-plasma: The *fluid* portion of the blood in which the corpuscles float is called *plasma*. The corpuscles can be filtered out under certain conditions, leaving the plasma for further examination. The chief method is by filtration at a temperature of 0° to 3° C.; but equally good results may be obtained by the addition to the blood of neutral salts in certain proportions, or by the use of the centrifugal machine. It differs from the serum in containing fibrinogen, but closely

resembles that fluid in reaction and appearance, its alkalinity, however, being somewhat less.

Blood-serum: The serum is the liquid part of the blood left after the separation of the clot. It is alkaline, transparent, of a yellow color, and of a specific gravity of about 1030. During the ordinary process of coagulation part of the serum remains in the clot and the rest is squeezed out. As the clot keeps on contracting for thirty-six hours or more, the amount of serum cannot be estimated till this time has elapsed. There is nearly as much serum by weight as there is clot in coagulated blood. As the chemical composition of serum is merely that of plasma less the fibrinogen, one description will suffice for both.

Properties and chemical composition of blood-plasma: Blood-plasma is a straw-colored, slightly viscid fluid, of a specific gravity of 1030, and alkaline (slight) reaction. Another property of plasma is that of *clotting*, to be discussed later. *Chemically*, plasma consists of a large percentage of water, holding in solution a number of inorganic salts, of which sodium chloride and sodium carbonate are the most abundant.

Besides the inorganic compounds, the plasma is rich in *three proteids*—serum-albumin, fibrinogen, and paraglobulin.

Serum-albumin is one of the so-called groups of native albumins, and represents the proteid portion of our food-supply after digestion and absorption into the blood have taken place.

Fibrinogen and *paraglobulin* belong to the group of globulins. Their source of origin is unknown. Their purpose in circulating blood is also doubtful; but they may be a source of nitrogenous food. At any rate, they play an important part in the coagulation of blood, as will be seen.

Carbohydrates in solution and *fats* in suspension or saponification are also present in the plasma. These, too, have been absorbed from the alimentary tract.

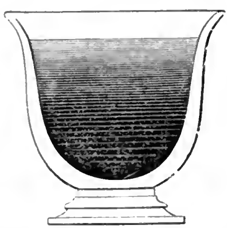
Other organic bodies, such as urea, lecithin, and cholesterin, representing *waste-products*, are held in solution by the plasma.

Carbon dioxide is found in solution in the plasma, representing the result of oxidation in the tissues. This gas is found in both arterial and venous blood, but in greater amount in the latter.

Small amounts of *oxygen* and *nitrogen* are also found in solution in the plasma. There is also probably a yellow pigment, independent of the hæmoglobin, which has not yet been exactly determined, though it is probably *cholesterin*. Similarly the *odorous* matter which gives the characteristic smell to the blood of different animals has not yet been discovered.

Gases of the blood: In the blood as a whole are found carbonic acid, oxygen, and nitrogen gases, there being from 50 to 60 volumes of these gases collectively in 100 volumes of blood. There are relatively more oxygen and less carbonic acid gas in arterial than in venous blood; but in both kinds of blood the carbonic acid exceeds the oxygen in amount. In arterial blood there is about 20 per cent. of oxygen, 40 per cent. of carbonic acid, and 1 to 2 per cent. of nitrogen; while in venous blood the oxygen forms from 8 to 12 per cent., the

Fig. 13.



Bowl of recently coagulated blood, showing the whole mass uniformly solidified (Dalton).

Fig. 14.

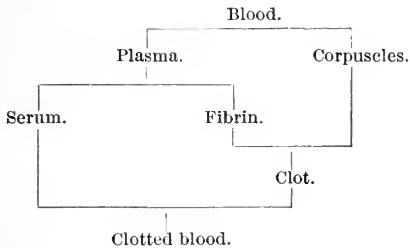
Bowl of coagulated blood after twelve hours, showing the clot contracted and floating in the fluid serum (Dalton).

carbonic acid about 45 per cent., and the nitrogen the same percentage as in the arterial. Part of both the oxygen and the carbonic acid is in solution, and the rest in weak chemical combination. Probably all the nitrogen is in solution.

Coagulation of blood: If blood be drawn into a shallow vessel and exposed to the air, it will become semisolid at the surface in two or three minutes. This jelly-like condition will extend to the sides of the vessel, and then throughout the entire mass, so that if the vessel be inverted the blood will not flow at the end of ten to fifteen minutes (Fig. 13).

Then drops of pale fluid (serum) begin to appear at the surface, and these unite to form an amount of fluid sufficient in an hour to float the clot, which meanwhile is contracting from the sides of the vessel. The serum continues to exude and the clot to contract for twenty-four to thirty-six hours. The color of the clot remains red, while the serum has a pale straw color (Fig. 14).

Clotting is due to the formation of a substance called *fibrin*, which appears as a mesh of fine fibrils and soon entangles the corpuscles. This mesh of fibrin contracts and squeezes out the watery elements of the blood to form serum, and holds the solid compounds, as shown by diagram as follows:



Conditions affecting coagulation: It has been found that some conditions hasten and others retard the time of coagulation.

Hasten.	Retard.
Moderate warmth, 100°-120° F.	Greater heat or extreme cold retard or entirely check.
Contact with foreign matters.	Contact with living tissues, especially bloodvessels.
Access of air.	Absence of air retards. After death by asphyxia blood remains fluid.
Rest.	Agitation of vessel retards.
Addition of moderate amounts of water.	More than twice the bulk of water.
	Addition of viscid substances—*i. e.*, glycerin, syrup.
	Addition of neutral salts, about 2 per cent. solution.
	Digestive ferments.
	Strong acids or alkalies.

Coagulation of blood—explanation: There are many theories to explain why the blood clots, but no one theory is perfectly satisfactory. The best we can do is to state such facts as are proven. As has been already stated, in the plasma of the blood there exists a proteid, called *fibrinogen;* there is also in the plasma a true, unorganized, organic ferment, called *fibrin-ferment.* When the blood is withdrawn from the living bloodvessels the fibrin-ferment acts on the fibrinogen and converts it into *fibrin,* the fibrin-ferment, like all true ferments, remaining unchanged. If the process were as simple as described, there would be no difficulty; but the change from fibrinogen to fibrin under the action of fibrin-ferment does not take place unless a *third* substance is present. The third ingredient is *paraglobulin,* already mentioned as existing in the blood-plasma. What part the paraglobulin plays is unknown. It is merely a proteid, and not a ferment, and yet is unchanged by the act of clotting. A possible explanation is that the paraglobulin unites with and renders inert some substance (unknown) which prevents the formation of fibrin in the living condition. After clotting has occurred the unchanged fibrin-ferment and the paraglobulin are found in the serum; the fibrinogen, now converted into fibrin, is the clot. The fibrin-ferment and paraglobulin are capable of still further activity if brought into contact with a fresh supply of fibrinogen. As to the origin of these three factors of coagulation there is no good explanation. It has been suggested that the leukocytes are the source of supply of one or more of the three substances, particularly fibrin-ferment. Certainly coagulation is more active in the presence of leukocytes.

In addition to the three factors given, the very important presence of *calcium salts* must not be forgotten. Although not an organic agent, in the process of coagulation the calcium salts blend with the fibrinogen, which under the influence of the fibrin-ferment becomes the fibrin.

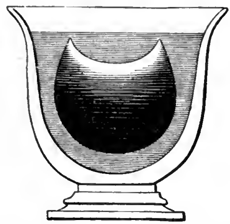
Blood-coagulum—*buffy coat:* If we examine under the microscope the blood-clot which has formed under ordinary circumstances, it is seen that the red corpuscles are caught by the meshes of fibrin and are uniformly distributed through-

out the clot. Many of the leukocytes have made good their escape into the serum. If we take a quantity of blood (Figs. 15 and 16) and retard the time of coagulation (horse's blood coagulates more slowly than human blood), we note that the upper part of the clot is much lighter in color. This is called the "buffy coat." The explanation of its formation is very simple. Owing to retardation of the coagulation, the red corpuscles have had a chance to settle toward the bottom. When seen under the microscope the upper layer, or buffy coat, of the clot is found almost free from red corpuscles.

FIG. 15.

Vertical section of a recent coagulum, showing the greater accumulation of blood-globules at the bottom (Dalton).

FIG. 16.



Bowl of coagulated blood, showing the clot buffed and cupped.

Why blood does not clot in the blood-vessels: As long as the endothelial lining of the blood-vessels is intact the blood does not clot; but if the endothelium is injured, a clot is formed at the site of the injury. Just what check on coagulation the endothelium plays is unknown, but it is none the less positive.

If a vein of some animal, preferably a horse, be carefully ligated in two places some inches apart, the blood within it will not coagulate for a long time, provided the endothelium is uninjured. This is not due to occlusion from the air simply. If such ligated vein with its contained blood be removed from the body and carefully opened, the blood may be poured from it into another vein similarly prepared, just as we pour fluid from one test-tube to another. Though the blood is thus exposed to the air, it will not coagulate till the endothelium is injured or loses its vitality.

If one accepts the theory that the fibrin-ferment is the result of disintegration of leukocytes, it is clear why blood does not clot within the bloodvessels, for there is no ferment unless a leukocyte disintegrates, the "normal" destruction of leukocytes being disregarded as a possible factor, owing to the small number so destroyed at any given time. On the other hand, if the endothelium be wounded, the leukocytes rush to the breach and are broken up; also, if the blood is shed, many leukocytes disintegrate in mass; thus in both instances a large amount of fibrin-ferment is liberated and clotting begins.

Blood—resume of its uses: The *red corpuscles* convey oxygen from the lungs to the tissues.

The *plasma* conveys the food, after absorption from the alimentary canal, to the tissues. The plasma also holds in solution the carbon dioxide and water (the result of oxidation) which it receives from the tissues, and carries these products to be eliminated by the skin, lungs, and kidneys. The plasma also holds in solution the urea and other nitrogenous bodies that are carried to and excreted by the liver and kidneys.

The *leukocytes* are protectors against the invasion of bacteria.

Thus it is seen that the various factors of the blood make up a whole—that is, a conveyor of supplies, a remover of waste, and a protector from invasion.

THE LYMPH.

Lymph is a pale straw-colored fluid that bathes all the tiny tissue-spaces of the body and is conveyed by lymph-vessels from the lymph-spaces to the blood. It is slightly alkaline, of a salty taste, and has no odor.

Composition: Lymph may be compared to a dilute blood free from red corpuscles, but rich in leukocytes. When the lymph-vessels of the lower animals, such as tadpoles, are examined under the microscope, it is found that the leukocytes are only present in the larger trunks; the smallest channels rarely contain particles or corpuscles of any kind. It is not

meant that all the constituents of blood are equally reduced when lymph is spoken of as a dilute form of blood. About the same proportions of salts, urea, and sugar are present in blood and lymph. Only about one-half as much serum-albumin and paraglobulin, and about one-quarter as much fibrinogen, are in lymph as are present in blood. *During digestion* there is a marked increase in fats and at such times the appearance of the lymph from the intestines is like milk, instead of being straw-colored. This form of lymph, known as *chyle*, owes its opacity to the distribution of this fatty matter in innumerable particles of very minute though nearly uniform size, measuring about $\frac{1}{30000}$th of an inch. Each particle is coated over with albumin.

Lymph *coagulates* in the same manner as blood, but more slowly and more feebly; a difference readily explained by the marked difference in amount of fibrinogen present. This property of coagulation is not possessed by the lymph in the smallest lymph-spaces nor by the chyle in the villi or lacteals near them. It is only developed as the fluids near the thoracic duct.

Lymph—sources: Between the individual capillaries of the blood-system there exist small intercellular spaces, into which the fluid portions of the blood are exuded owing to the differences in pressure. This exudate, plus the leukocytes that have left the bloodvessels by emigration, makes up the lymph proper. In addition to the lymph proper, the lymph that fills the lacteals of the intestinal villi absorbs some of the products of digestion, especially the fats. This portion of the lymph that has absorbed the fats is milky in appearance, and is called "chyle." The *chyle* and lymph proper are carried along in their respective channels and are mingled together just before the entire fluid is poured into the vein at the root of the neck.

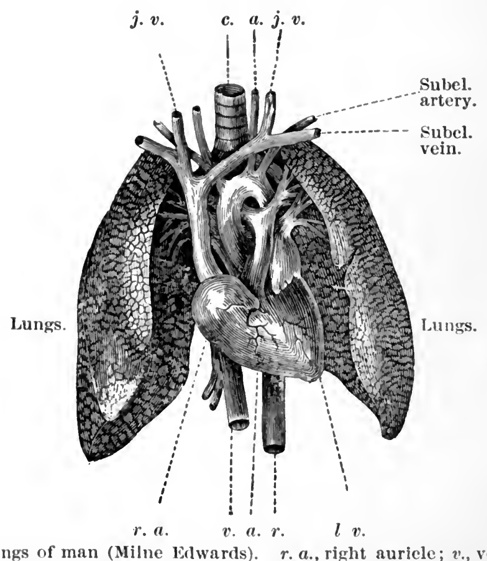
Uses: The lymph bathes all portions of the body not reached by the blood. Hence the lymph conveys the nutrient ingredients of the blood to all cells not directly bathed by the blood. The "chyle," or lymph of digestion, absorbs nutrient materials (mostly fat) from the intestines and pours this food into the blood-current, to be universally distributed.

The lymph gathers up the waste-materials of the cells surrounding the lymph-spaces and pours this waste into the blood, to be eliminated by the skin, lungs, and urine.

CIRCULATION OF THE BLOOD.

The **circulation of the blood** is the course which the blood, as a transporting medium, follows in taking food and air to the tissues and bringing away the used-up material for excretion, and returning when freshly charged with oxygen and food.

FIG. 17.



Heart and lungs of man (Milne Edwards). *r. a.*, right auricle; *v.*, vena cava inferior; *a.*, right ventricle; *r.*, aorta; *l. v.*, left ventricle; *j. v.*, jugular vein; *c. a.*, trachea and carotid artery.

The **circulatory apparatus** consists of:

(1) The heart, which propels the blood;

(2) The arteries, which convey it from the heart to the different parts of the body;

(3) The capillaries, a network of inosculating tubules interwoven with the substance of the tissues and bringing the blood into intimate contact with it;

(4) The veins, which collect the blood from the capillaries and return it to the heart.

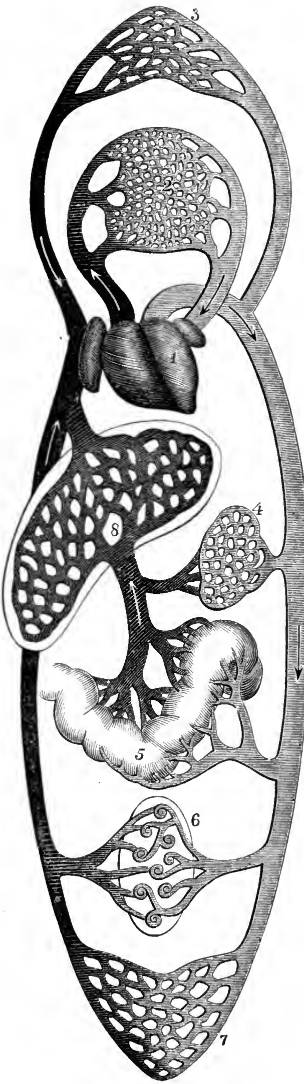


Fig. 18.

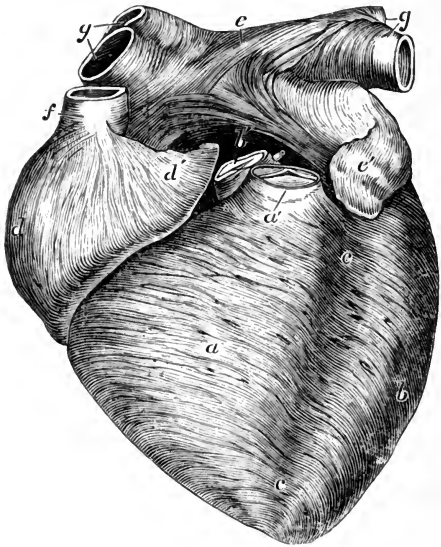
Diagram of the circulation: 1, heart; 2, lungs; 3, head and upper extremities; 4, spleen; 5, intestine; 6, kidney; 7, lower extremities; 8, liver (Dalton).

Course of the blood: As the motion of the blood is in a circle, it is immaterial at what part of the vascular system we begin its study. Starting, for convenience, with the blood as it leaves the lungs, we find that the blood enters into the left auricle from the pulmonary veins, thence passing the open mitral valve into the left ventricle (Figs. 17 and 18). Upon contraction of the ventricle the mitral valve is closed and the aortic valves thrown open, so that the blood is thrown into the aorta, and thence through the systemic arterial circulation into capillaries and on into veins, the systemic veins finally joining to fill the venæ cavæ, and from them the right auricle. From the

right auricle the blood passes the tricuspid valve into the right ventricle, whence it is thrown through the pulmonary artery (guarded by the pulmonary semilunar valves) into the pulmonary capillaries, and thence into the pulmonary veins, whence it started. Thus we have in reality two circulations, the systemic and the pulmonary.

Also we see that the blood goes through one set of capillaries—the lungs—to be purified of waste-products and re-

FIG. 19.



Anterior view of heart (Quain).

oxygenated; and another set—the systemic capillaries—where the oxygen is lost and the waste-products gathered up.

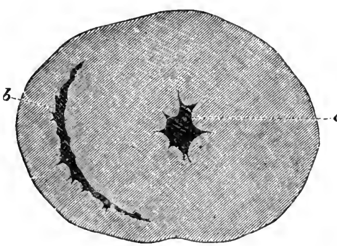
Furthermore, the student will take note that the blood which enters the splenic and intestinal arteries from the aorta passes through *two sets* of capillaries before returning to the general venous circulation: the *first set* of capillaries is in the *alimentary canal* and *spleen*, whence the blood returns, is accumulated in the portal vein, and carried to the liver. In

the latter organ the blood passes through a *second set* of capillaries, to be gathered into the hepatic veins, and finally emptied into the inferior vena cava. While in the first set (intestinal) of capillaries the blood gives up its oxygen to nourish the walls of the intestine, and takes up in exchange the carbon dioxide (waste of intestinal activity) and certain of the nourishing products of digestion. On passing through the hepatic capillaries some of the food-products are left behind in the liver for storage, while others are carried on into the circulation.

The **heart** (Fig. 19) is a muscular organ situated in the thorax, where it lies between the lungs within the pericardial sac, and rests upon the diaphragm, its larger portion lying somewhat to the left of the midline of the body. It is conical in form, and is so suspended by the great vessels that the apex points to the left and downward. Its size is about that of the closed fist (weight, in adults, about ten ounces).

It is divided by a septum into two cavities, not connected, the right and the left (Fig. 20). Each of these in turn is subdivided into two parts, the auricle and the ventricle.

Fig. 20.



Transverse section of a bullock's heart in the state of cadaveric rigidity. *a*, cavity of the left ventricle; *b*, cavity of the right ventricle.

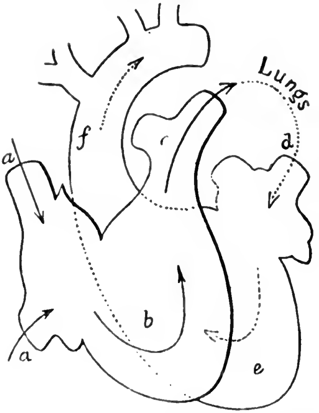
The *auricles* are thin-walled cavities, whose function is to receive the blood from the veins and pour it into the ventricles.

The *ventricles* are surrounded by the most powerful portions of the heart-muscle, **the walls** of the left being much stronger and thicker than those of the right ventricle. The auricles contain about four ounces, the ventricles about six ounces.

Action of the auricles: During the period of rest of the heart, blood flows freely from the veins into the auricles and thence into the ventricles, the auriculo-ventricular valves offering no resistance; but the influx is so strong that by the

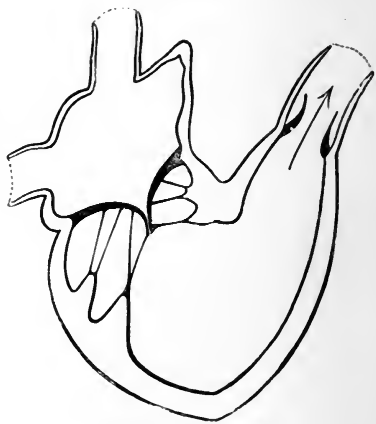
time the heart begins to contract the auricle is quite filled and the ventricle partially. The contraction of the auricle is sudden and very quick, commencing at the great veins and extending toward the ventricular opening. Both auricles contract simultaneously. There are no valves at the openings of the venæ cavæ into the auricles, but the blood *does not regurgitate* for the following reasons:

Fig. 21.



Course of blood through the heart. *a*, *a*, vena cava, superior and inferior; *b*, right ventricle; *c*, pulmonary artery; *d*, pulmonary vein; *e*, left ventricle; *f*, aorta.

Fig. 22.



Valves of the heart.

(1) The power of the auricular contraction is not sufficient to cause a reflux.

(2) The muscular coat of the great veins near the heart contracts, and helps to prevent this regurgitation.

(3) The weight of the incoming blood opposes.

(4) Valves in the veins oppose, and the Eustachian valve partially guards the inferior vena cava.

Action of the ventricles: The ventricle is distended during its period of rest by the flow of the blood from the veins and by the auricular contraction; and its contraction seems continuous with that of the auricle, so immediately does it suc-

ceed. The ventricular contraction is slower and probably completely empties the cavity. The ventricles contract simultaneously. The shape of the ventricles is changed: as the heart-muscle becomes hard and rigid in contraction the section of its base becomes circular, instead of elliptical, as it is during repose; the ventricles shorten and twist to the right, and the form is conical. As the organ relaxes it returns to its former position and shape, that of a cone with elliptical base. This shortening of the ventricles in contraction is compensated by the lengthening of the great vessels at the base as they become distended by the load of blood.

The valves: In considering the *functions* of the valves of the heart one must bear in mind constantly that the organ is a pump whose office is to force the blood in one direction. There are four principal valves—two auriculo-ventricular, and two in the great arteries, the aorta and the pulmonary artery: (1) As the ventricle fills the *auriculo-ventricular* valves are floated up from the sides of the ventricle in such manner that their edges are in contact, cusp to cusp. As the ventricle contracts more violently, pressure is brought upon the valve, so that not only is the edge in contact, but also portions of the surfaces of the cusps. These valves are of considerable area, and are guyed in position by the *chordæ tendineæ*, which spring from the papillary muscles, so that eversion of the valve into the auricle is impossible. (2) The *semilunar valves* form a guard against the return of the blood to the ventricle at the pulmonary and aortic openings of the ventricles. These valves are forced open by the ventricular contraction, and through them the blood rushes to distend the elastic walls of the large arteries. The pressure of the blood under this elastic grasp is sufficient to throw the cusps of the valves into action. The corpora Arantii are useful in making a perfect closure of the valve, though not absolutely essential. A part of the weight of this pressure is borne by the thick ventricular wall, which forms a ring, from the outer edge of which the artery springs, while the valves are attached to the inner edge.

Under some circumstances the tricuspid valve does not entirely close, but allows a certain amount of regurgitation of

blood. This occurs in conditions of disease or of violent exertion, in which the lung-capillaries are overcharged with blood. The leakage of the valve is conservative, and relieves the pressure upon the delicate capillaries of the pulmonary alveolæ. Pulsation in the jugular veins indicates this regurgitation. The condition is not pathological, and with altered conditions disappears.

The **arteries** are continuous hollow tubes leading from the heart. They are surrounded by a dense fibrous coat externally, and are lined internally by a smooth endothelial lining; between these is an elastic layer of fibrous tissue, which has interlaced in its structure muscle-cells arranged transversely around the vessel. Each artery has its own *vasa vasorum*, or nutrient vessels, and is usually enmeshed in a plexus of sympathetic nerves, "vaso-motor" nerves. Owing to the various branches given off from the arteries, the calibre of these vessels diminishes as we leave the heart. The smallest arteries have been designated *arterioles*, and at their distal ends the arterioles cease and the capillaries begin.

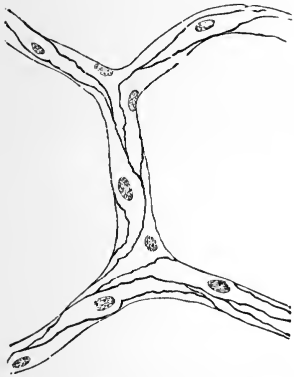
In the *large* arteries the elastic tissue is in excess of the muscle-tissue, whereas the reverse holds true in the arterioles. The principal difference between the larger and the smaller arteries is in the structure of their middle coat. In the smaller arteries this is composed exclusively of muscular fibres. In arteries of medium size it contains both muscular and elastic tissue; while in those of the largest calibre it consists of elastic tissue alone. The larger arteries, accordingly, have much elasticity and but little contractility; while the smaller are contractile and less elastic. The variation in thickness of this middle coat is chiefly responsible for the differences in the thickness of the walls of the larger and smaller arteries.

The capillaries: The capillary blood-vessels (Fig. 23) are channels of very small but variable size, but usually of about sufficient calibre to permit just the passage of the red and white corpuscles. They are usually composed of a single layer of endothelial cells joined at the edges, though near the arteries and veins there is sometimes an elastic fibrous coat.

A sympathetic nerve-plexus surrounds these vessels. The capillaries form a complicated network in the tissues, and the mesh of the net varies in shape and size greatly with the vascularity and function of the tissue.

The veins: In structure the veins are similar to the arteries, being composed of three coats—an inner, a middle, and an exterior—of similar nature; but they contain a smaller quantity of muscular and elastic fibres and a larger portion of condensed connective tissue. That is, their inner and middle coats are thin, while the outer coat is relatively thick. Consequently they are less elastic and contractile, but more compressible than arteries. Veins collapse, while arteries remain open when not distended by blood. Valves (Fig. 24) occur in most of the veins; these are so placed as to prevent the blood from tending to flow backward. The valves are so placed as to aid the onward progress of the blood in the veins, the pressure of neighboring muscles forcing forward the blood, which cannot regurgitate past the valves.

Fig. 23.



Fine capillaries from the mesentery.

Fig. 24.

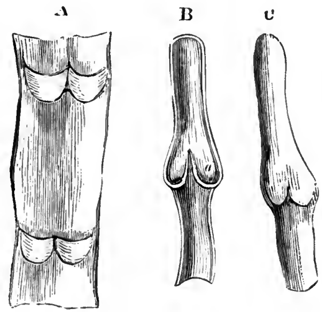


Diagram showing valves of veins. A, part of a vein laid open and spread out, with two pairs of valves. B, longitudinal section of a vein, showing the apposition of the edges of the valves in their closed state. C, portion of a distended vein, exhibiting a swelling in the situation of a pair of valves (Quain).

Size of the bloodvessels: With the division of the arteries

into branches the sectional area of the branches is greater than that of the stem. Of the veins the same is true, while the total sectional area of the capillary system is much greater than that of either. For purposes of simile the comparison may be made of two funnels placed base to base. In numbers one may consider the sectional area of the aorta as 1; of the venæ cavæ, 2 or 3; of the capillaries, (about) 500. An individual capillary has been estimated as being $\frac{1}{2}$ mm. long, and from 5 to 20 μ in diameter.

Forces maintaining circulation: The heart, as has been shown, is a force-pump, and at each contraction injects a fresh volume of blood into the arteries; during the repose of the heart it fills up with blood from the veins which has already travelled the circuit.

The *heart* is the prime and important factor in maintaining circulation, and is capable of forcing, unaided, the blood through the entire circuit; but in addition we find *subsidiary forces* assisting the outward flow of blood:

(1) *Arterial resiliency:* At each beat the ventricles inject a fresh quantity of blood into the already filled arteries. To make room for this surcharge of blood the large arteries, owing to their elasticity, are dilated by the increased amount of blood. During the repose of the heart the arteries contract by virtue of the recoil of their elastic fibres and drive the blood on. This action of the arteries converts the intermittent character of the blood-stream into a steady flow by the time the capillaries are reached.

(2) *Contraction of muscles:* The skeletal muscles, during the ordinary activities of the body, contract, and so compress the veins lying between them. This compression drives the blood out of the veins, but only in the proper direction, as the valves of the veins prevent the reverse flow.

(3) *Cardiac suction:* During the period of repose the opening out of the heart-cavity is sufficiently strong to exert a decided *suction* on the blood in the veins.

(4) *Thoracic suction:* During the expansion of the chest in inspiration a tendency to a vacuum is produced, which exerts a suction on the large veins within the thoracic cavity. This fact must always be borne in mind by the surgeon

when operating on the neck. Should a large vein be wounded, it must be instantly closed, lest by reason of this suction air be drawn into the vein. If air should in this way enter the proximal part of a wounded vein, it would be hurried along to the heart, and, there expanding, cause serious trouble or even death.

(5) A slight rhythmical contraction of the veins.

Speed of the blood: In the *arteries* it has been estimated that the blood in the large arteries travels at the rate of about 300 to 500 mm. per second. As the blood advances in the arteries the speed decreases gradually.

In the *capillaries*, owing to their much larger aggregate diameter (500 : 1), the speed falls very low, and is estimated to be $\frac{3}{4}$ of a mm. per second.

In the *veins* the speed increases as we approach the heart, and in the venæ cavæ is found to be from 125 to 200 mm. per second.

With these figures as a basis, it has been calculated that a given particle of blood occupies about a half minute of time in going the round of the body. One second of the half minute is used in passing the systemic capillaries, another second in traversing the pulmonary capillaries.

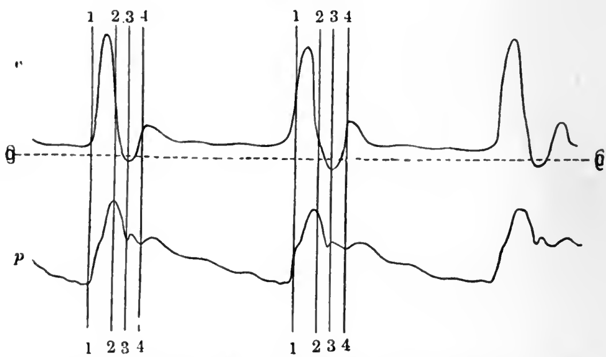
It has been found by experiment on animals that there is a **ratio** between the **blood-speed** and **-pressure** which may be direct or inverse. Any influence which increases or diminishes the force of the heart will at the same time increase or diminish both the velocity and the pressure of the blood; while any influence which increases or diminishes the resistance to the arterial flow will make the velocity and the blood-pressure vary in an inverse ratio to each other. Other things being equal, both the pressure and the velocity in the large arteries increase markedly during systole and diminish greatly during diastole. Very near the heart the velocity is greatest at the beginning of systole, then drops to almost nothing toward the end of systole, and then, regaining speed, flows at an almost even pace during diastole (Fig. 25).

Blood-pressure: By means of *manometers* the blood-pressure has been determined. It is greatest in the arteries nearest the heart, and gradually diminishes, until in the veins empty-

ing into the heart it is found to be zero; or even a slight negative pressure or suction may be present.

The figures are as follows: pressure in the large arteries supports a column of mercury 150–200 mm. high (about four pounds to the square inch). In the capillaries, 30–50 mm. of mercury. In the distal veins, 20 mm. of mercury, gradually falling as we approach the heart.

FIG. 25.



Tracings of variations of rapidity and of pressure of blood in the carotid of a horse, obtained by Chauveau and Lortet. The line *v* represents the curve of the rapidity of the blood; and *p* the curve of arterial pressure. The figures and vertical lines represent corresponding periods in the tracings (McKendrick).

The *cause* of the high pressure in the arteries is due to the force of the blood injected from the heart behind, and the resistance of the capillaries in front. Although the blood is pumped into the arteries in *intermittent* jets, when a *small* artery is cut the blood spurts from it in a *continuous* jet. The reason for this is the *elasticity* of the arterial walls, these being put on the stretch by the blood forced into them at considerable pressure, and contracting again during the period of heart-rest, thus enabling the arteries to keep the blood under elastic compression. The capillaries, though collectively of much greater area than the arteries, by reason of the friction they offer to the blood-stream maintain a less degree of tension.

Conditions modifying arterial tension: (1) The rate of the heart-beats, by keeping the arteries fuller or less full, will modify the blood-pressure in the arteries.

(2) Vaso-motor changes, by increasing or decreasing the friction offered the arterial blood, vary the tension in the arteries.

(3) The amount of blood in the system must to a great extent determine the limits of arterial pressure. In great exsanguination the arterial pressure is quite low.

(4) Motion of the thoracic walls in breathing necessarily changes the arterial tension by the pumping force exerted by this motion.

The blood in circulation: While circulating in the arteries and veins the blood travels at too great a speed to admit of careful examination; the leukocytes in spherical form and the red corpuscles, bowled along indiscriminately, pass the eye too rapidly for any peculiarities to be noticed.

The capillaries of the web of a frog's foot can be easily examined with a microscope. In these the speed of the blood is slow, and ample time is given to study the particular corpuscles.

On entering the capillaries the red cells are seen to occupy the central portion of the stream of plasma. That portion of the plasma in contact with the capillary walls is seen to travel much slower than the central portion, owing to the friction presented by the capillaries. This is known as the "inert layer" of plasma. The *corpuscles*, being comparatively heavy, are crowded in the centre of the stream. That the centre of the stream travels faster than the periphery is shown by the fact that if we watch three corpuscles floating abreast, in a moment or two the centre corpuscle forges ahead and leaves its companions behind.

Some of the capillaries are so small that the red corpuscles pass in single file; some may even be so small that the corpuscle is squeezed up and elongated that it may glide through the constriction; on entering a vessel of larger calibre the corpuscle, owing to its elasticity, resumes its shape.

The *leukocytes* in the arteries are carried along passively in spherical shape, but on entering the capillaries are crowded

into the inert layer by the heavier red corpuscles. In the inert layer they change their shape and flatten out against the capillary-wall. They now exhibit their amœboid movement, and perchance one may be seen sending its pseudopodia through the cement-substance between the endothelial cells of the capillary-wall—in other words, puncturing the capillary. Having projected a pseudopod through the capil-

Fig. 26.

Capillary plexus in a portion of the web of a frog's foot (magnified 110 diameters). 1, trunk of vein; 2, 2, 2, its branches; 3, 3, pigment-cells.

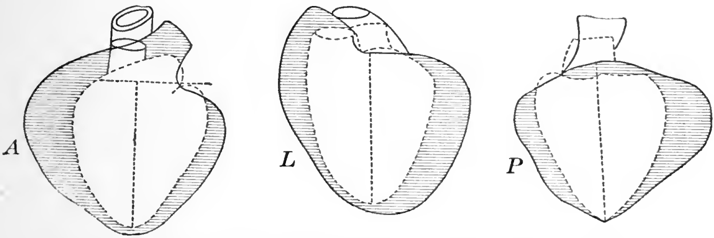
lary-wall, the leukocyte proceeds to draw the rest of its body through, and then escapes into the tissue-spaces. The cement-substance closes spontaneously and no leak occurs.

Of course, it must not be supposed that all the leukocytes escape from the capillaries. Only a small portion undergo this "emigration," the majority going on with the blood-current into the veins (Fig. 26).

The Heart (see also p. 51).

Action of heart: During ordinary average life the heart beats about 72 times per minute. During muscular activity and after eating or under excitement the rate increases;

FIG. 27.



Projection of a dog's heart. Shaded portion indicates appearance of diastole; white portion, of systole. *A*, anterior surface; *L*, lateral surface; *P*, posterior surface (McKendrick).

during sleep it is lowered. At birth it is about 130 per minute; at three years, 100; in adult life, 72; in old age, 65.

FIG. 28.

Converging spiral fibres at the apex of the heart. The direction of the arrows indicates that of the rotating movement of the heart at the ventricular systole.

This rate is varied from time to time by conditions of bodily health and by environment. The heart-beat in women is somewhat more rapid than in men. The relative frequency of heart and respiratory action is about three or four heart-beats to one respiratory act.

The *heart-beat* is made up of a contraction—*systole*—and a repose—*diastole*. During systole the heart becomes hard and diminishes in size, not only transversely, but longitudinally (Fig. 27), thus resembling voluntary muscle. This can be proved by experiment, though it seems false to any one who has examined a heart while in place in a living animal. In such cases there is an apparent *elongation* of the heart during systole, due, however, to the forward motion of the whole heart during systole. This forward motion is a result of

the twisting of the apex of the heart upon itself during systole (Fig. 28) from left to right, returning during diastole. It is caused by the spiral arrangement of the muscular fibres at the apex.

The combined systole and diastole is called the *cardiac cycle,* and consists of four factors: (1) systole of the auricles, (2) diastole of the auricles, (3) systole of the ventricles, and (4) diastole of the ventricles.

The **auricular systole** is rapid, and forces the blood into the still quiescent ventricles. On completion of the auricular systole the auricles expand and remain quiet during the systole of the ventricles, which begins the moment the auricles cease contracting.

The **ventricular systole** is more forcible than that of the auricles, but the ventricles remain in contraction longer than do the auricles. During ventricular systole the blood is forced into the arteries. At the close of the ventricular systole the ventricles dilate. The auricles do not take up work again at once, but there is a period during which the entire heart is in repose. After this repose the auricles again contract and a new cycle is begun.

Time of cycle: If we assume the average heart-beats to be 72 per minute, each cardiac cycle occupies 0.8 of a second. The contraction of the auricles lasts 0.1 of a second. The contraction of the ventricles lasts 0.3 of a second; and the repose of the entire heart, 0.4 of a second. Thus of the entire 0.8 of a second, the auricular systole lasts 0.1 of a second and the diastole 0.7 of a second; the ventricular systole 0.3 of a second and the diastole of the ventricles 0.5 of a second. The combined systole of the auricles and ventricles, 0.4 of a second; and the total repose of the whole heart, 0.4 of a second. If the heart-rate be increased, the ventricular systole remains about 0.3 of a second: so we see that an increase in the heart-rate is made at the expense of the diastole.

Heart-sounds: The first sound is heard best over the apex of the heart. It is of a dull, prolonged, booming character. The second sound is heard immediately after the first, and is a sharp, quick, almost clicking sound; it is heard most clearly

over the base. The sounds are said somewhat to resemble that expressed by *lubb-dup*.

The *first sound* is synchronous with the ventricular systole and with the closure of the auriculo-ventricular valves; it is supposed to be made up in reality of two sounds—a valvular one, caused by closure of the auriculo-ventricular valves, and a muffled one, due to contraction of the muscular fibres of the ventricles. That it is due in part to the action of the valves is proved by the fact that the sound is altered when the valves are diseased or are artificially prevented from closing. That muscular contraction of the heart produces a sound can be demonstrated by the cardiophone. This is the only way of accounting for the sound, though of an altered character it is true, which is produced at the beginning of systole by a heart from which the auriculo-ventricular valves have been experimentally removed.

The *second sound* is synchronous with the closure of the semilunar valves, and is caused by this action. It is heard most distinctly opposite these valves, and is propagated upward along the great vessels to which they are attached. There is no doubt that it is caused solely by their closure.

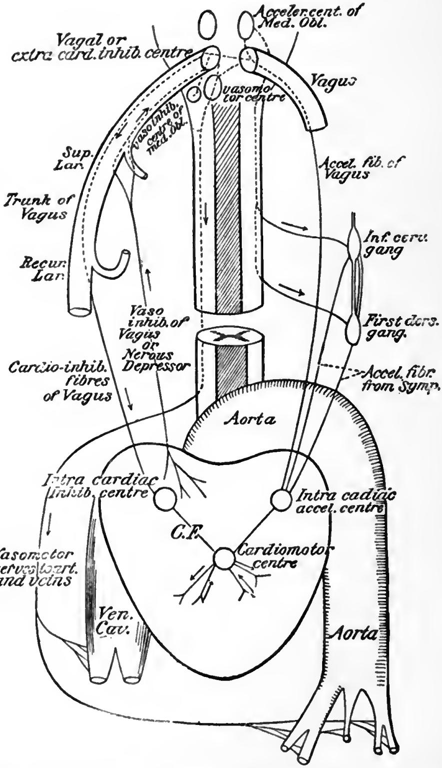
Blood-supply of the heart: By the coronary arteries, which arise in the sinuses of Valsalva circumferential to the leaves of the semilunar valves. They do not receive blood during systole; but during diastole from pressure of the blood due to the elasticity of the arteries, especially that of the aorta. The blood is returned to the right auricle through the coronary sinus and cardiac veins.

Force of the heart: The left ventricle exerts more than twice as much power as the right. The exact intraventricular pressure in man has not been ascertained. The expansion of the heart exerts a negative (or suction) pressure which aids the onflow of the blood, especially from the lungs to the left auricle and ventricle. The intra-auricular pressure is very much less than the intraventricular, and there is a negative pressure during diastole in the auricles.

Estimated in foot-pounds, each ventricular contraction represents three and a half to four and a half foot-pounds. In twenty-four hours this is estimated to equal more than one

hundred and twenty foot-tons. In another light, if the blood is one-twelfth of the body-weight, and if the amount of blood

Fig. 29.



Diagrammatic view of the nerves influencing the action of the heart. The right half represents the course of the inhibitory, and the left the course of the accelerating nerves of the heart; the arrows showing the direction in which impressions are conveyed. The ellipse at the upper extremity of the vagus, looking like a section of the nerve, is intended to represent the vagal nucleus or centre. In this diagram the nerves are incorrectly made to cross, instead of passing behind, the aorta.

pumped with each ventricular contraction is six ounces, in an ordinary man an amount of blood equal to the total blood

of the body will pass through the heart in about half a minute.

The amount of blood poured out by the systole of the ventricles is called the "pulse-volume."

Innervation of the heart: This matter is somewhat undecided at present, for the reason that many of the results must be obtained from experiments upon the hearts of cold-blooded animals. We do know that the mechanism of rhythmical contraction is contained within the heart itself. Nerve-ganglia are demonstrated in the frog's heart which are essential to its action; similar ganglia exist in the human heart. These ganglia are connected with fibres from the pneumogastric (or vagus) nerve and with the sympathetic system (Fig. 29).

The *cardiac inhibitory* nerve is a branch from the *pneumogastric* nerve running to the heart. It has an *inhibitory* or slowing effect upon the heart; for if we cut the nerve the heart becomes more rapid, and if we stimulate (Fig. 30) the

Fig. 30.

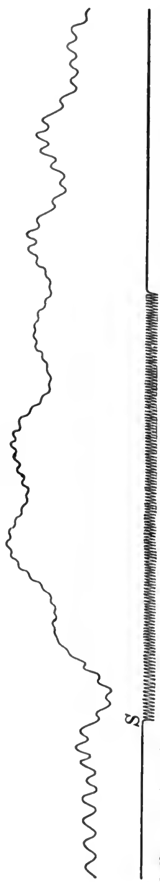
Effect of stimulation of the pneumogastric nerve upon the action of the heart in a frog. To be read from right to left.

peripheral end of the nerve we slow the heart again. This action may be traced to the medulla oblongata, where a cardio-inhibitory centre is located. That the inhibitory influence of the cardiac fibres of the vagus is not directly exerted upon the heart is proven by the length of time elapsing between the application of the stimulus and the appearance of the inhibitory effect. In some cases even two entire heart-beats occur after a strong stimulus is applied before the heart stops, indicating that some resistance must be overcome, the inhibitory fibres acting upon inhibitory centres in the heart itself. Stimulation of the vagus not only slows the heart's action, but modifies it. Systole and diastole are lengthened; the input and output of the ventricle are diminished; the diastole pressure and volume of blood in the ventricles are in-

creased, and ventricular become less frequent than auricular contractions, the latter being often twice as numerous.

Certain fibres of the *sympathetic* from the cervical and upper dorsal spinal cord pass to the heart. If these fibres are left after all other nerve-connections of the heart are cut away, stimulation of the spinal cord will cause the heart to become rapid. These are known as *accelerator nerves.* These accelerating nerves act less powerfully than the inhibitory ones. They not only accelerate the heart's action, but increase the force of the beat and the output (Fig. 31).

Fig. 31.



Effect produced by stimulation of peripheral end of the accelerating nerve of the heart. The heart beats quicker. Stimulation begun at *S* (Landois).

The *cardiac depressor* nerve is a centripetal nerve running from the heart to the vaso-motor centre in the medulla. Its purpose is to stimulate the vasomotor centre to dilate the peripheral arteries. The nerve is "stimulating" only when the heart is laboring against too high tension produced by unusually high *peripheral resistance.*

Vaso-motor Nerves.

Arterial contraction and dilatation: The muscular coats of the peripheral arteries do not undergo a rhythmical contraction and dilatation, but only contract so as to diminish the calibre of the arteries and thus limit the supply of blood to a given part of the body. On the other hand, the muscle-fibres relax and allow the arteries to dilate when the given part demands more blood to satisfy its activities. Hence it is a perfectly normal condition to have the arteries of one part of the body dilated, while the arteries supplying another part

are contracted, depending on which part of the body is functionating.

By *tone* of the arteries is meant their average normal state of contraction.

The **nerve-supply** of the muscular coats of the arteries is through the "vaso-motor" nerves. They are of two varieties according to their function, *vaso-constrictor* and *vaso-dilator*. These nerves (vaso-constrictor and vaso-dilator) run together in the same sheath, and are part of the sympathetic system.

They have their origin in the vaso-motor centre in the medulla. They pass down the spinal cord to emerge at different levels, thence to be distributed to all the different arteries. Just before leaving the spinal cord there are secondary vaso-motor centres in the course of these nerves. Close to the wall of the artery to be supplied there is a third (ganglionic) centre for vaso-motor action. On emerging from this third centre the vaso-motor nerve breaks up into its terminal filaments which are distributed to each muscle-fibre.

Action of vaso-motor nerves: It must not be supposed that contraction and dilatation of the muscle-fibres are active acts on their part depending upon whether the vaso-constrictor or the vaso-dilator fibres are stimulated. It is true that contraction of the muscle-fibre is an active act depending on stimulation from the vaso-constrictors; but were this stimulus removed the muscle-fibres would relax and the artery dilate passively, owing to the presence of blood within it.

We find that the vaso-constrictors act continuously with more or less intensity. The action of the vaso-dilators is only occasionally called into play, when marked dilatation of the bloodvessels is called for. Also the dilators do not directly act upon the muscle-fibres, causing them to dilate; but act upon and *inhibit* the action of the vaso-constrictors, thus allowing a passive dilatation of the arteries because the constrictor action is removed.

The vaso-motor centre in the medulla is the prime centre, and the only one acting during normal life. The secondary centres in the cord only assume control if the primary centre is destroyed or its connection severed. The third centres

(close to the artery) only act if the secondary centres are destroyed or cut off.

Pulse.

The **pulse** is the alternate expansion and contraction of the artery ("excursion of the wall of the artery") resulting from the fresh injection of blood at each ventricular systole. Of course, the pulse-rate is the same as the number of heart-beats.

A number of various terms are used to describe the character of the pulse:

Frequent or infrequent=number of beats per minute;

Regular or irregular=whether beats follow successively or not;

Intermittent=beats skipped at regular intervals;

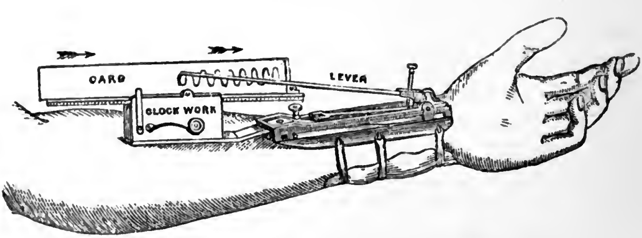
Large or small=amplitude of excursion of wall of artery;

Quick or slow=whether wall of artery rises rapidly or not.

Wiry, Incompressible, Hard,	are synonymous terms denoting a high-tension pulse. Their opposites are	gaseous, compressible, soft.

The sphygmograph: While an experienced physician can appreciate slight variations in the character of the pulse, it

Fig. 32.

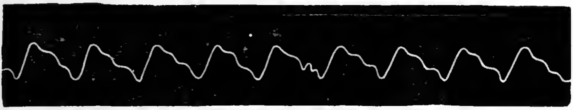


Marey's sphygmograph applied to the arm (Marey).

is only by means of the graphic method that the different kinds of pulse can be successfully investigated and records kept. The sphygmograph (Fig. 32) is an instrument which

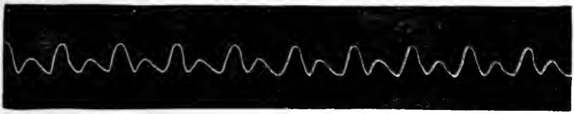
measures the succession of the alternate dilatation and contraction of an artery, known as the pulse; and, magnifying these movements, registers them on a surface moving at a uniform rate by clockwork. The resultant tracings are in the form of a wavy line, the irregularities of which show variations of the pulse too slight to be appreciated by the most experienced fingers (Figs. 33 and 34).

FIG. 33.



Trace of the radial pulse, taken by the sphygmograph.

FIG. 34.



Dicrotic pulse of typhoid fever (Marey).

Extinction of pulse: In health the pulse gradually lessens as we get further from the heart, and is entirely lost where the arteries break up into capillaries. There is no pulse in the capillaries nor a true pulse in the veins.

Venous pulse: Were the venous walls rigid, there would be a respiratory pulse in the veins. In deep and infrequent respiration, as in partial asphyxiation, the jugular veins may be seen to be distended in expiration and collapsed during inspiration, thus forming an abnormal venous pulse. The cause is the pressure of the atmosphere upon the flaccid vein, it being easier to empty the vein than to fill it under the sudden vacuum produced by the act of inspiration drawing the blood from the surface veins into the thorax. The veins are thus emptied, and, being flaccid, are depressed by atmospheric pressure.

This **suction power** of the inspiratory vacuum in the thorax extends over a small region only; roughly speaking, the neck and axilla. This is the so-called "dangerous surgical region;" for if a vein is punctured, air enters the blood-current and is carried to the heart, and death results. But the flaccidity

of the vein naturally causes a collapse of the wall, and air will not readily enter unless the wall remains rigid from artificial or abnormal causes. If the vein can collapse, not being held open by connective tissue or fascia, or artificially or as a result of calcareous infiltration, no air will be allowed to enter the vessel, and the only sign will be an expiratory intermittent hemorrhage.

"CIRCULATION" OF THE LYMPH.

The lymphatics: The blood-capillaries as they pass through the various tissues of the body are surrounded by small open spaces, called *lymph-spaces*. These spaces are the interstices between the various component parts of the body-tissues. The lymph-spaces form the open mouths of microscopic lymph-capillaries, that closely resemble the blood-capillaries in structure. The lymph-capillaries run together and go to form larger channels, known as the "lymphatics" or "lymphatic vessels"; this arrangement is comparable to the formation of veins from blood-capillaries (Fig. 35). These lymphatic vessels converge finally into two main channels—thoracic duct and right lymphatic duct—that pour their contents into the venous system at the junction of the internal jugular and subclavian veins on the left and right sides of the neck respectively.

The *lymphatic radicles* (Fig. 36) *of the intestine*, although not differing in structure from lymphatics elsewhere in the body, are called "lacteals," because of the milk-like appearance of the lymph they contain.

The lymphatics of the lower extremities, the trunk of the body, and the intestinal tract, go to form a long channel, the *thoracic duct*, which ascends along the front of the vertebral column to the root of the neck on the left side. Here the thoracic duct is joined by lymphatics draining the left side of the head and left upper extremity. The combined channel empties into the left innominate vein at the point of junction of the left internal jugular and left subclavian vein.

The lymphatics of the right side of the head and right upper extremity join to form the *right lymphatic duct*—a short

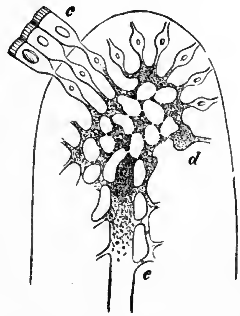
structure, one and a half inches long, emptying into the right innominate vein.

Stomata and pseudostomata: In certain parts of the body there have been found openings, or *stomata*, by which a direct communication exists between the lymphatic capillaries and certain cavities previously supposed to be entirely closed. We say that absorption takes place through *pseudostomata* when fluids pass into the lymphatic system through the intercellular cement-substance of the epithelium or endothelium covering membranes. Stomata have been found in the peritoneum and pleura.

FIG. 35.

Lacteals and lymphatics, during digestion.

FIG. 36.



Diagrammatic representation of the origin of the lacteals in a villus. *e*, central lacteal; *d*, lymph-channels; *c*, columnar epithelial cells, the attached extremities of which are directly continuous with the lymph-channels.

Flow of lymph: Thus we see that the lymph flows from the tissue-spaces into the veins at the root of the neck; so it is not justifiable to speak of the "circulation of the lymph," as there is no return-current. The lymph is formed in the lymph-radicles, and ceases to be lymph proper as soon as it enters the venous blood. But new lymph is constantly formed, and so there is a steady onward flow.

Fig. 37.

Valves of the lymphatics (Sappey).

Structure of lymphatics: The lymphatic channels closely resemble the veins in structure, but are much thinner walled and possess a much larger number of valves (Fig. 37).

Sources of lymph: The lymph present in the lymph-spaces is made up of the exudation of a certain amount of blood-plasma through the walls of the capillaries, together with the leukocytes that have emigrated from the capillaries. It is probable also that certain portions of the body-tissues may be found in the lymph, which, though they have fulfilled their functions and have to be removed, are not entirely waste-products. They may be capable of reorganization in the lymph-glands and may be absorbed by the lymphatics for this purpose.

The lymph in the radicles of the intestines is composed of the blood-plasma and leukocytes that have left the intestinal capillaries, plus an innumerable number of microscopic globules of *fat* that have been absorbed from the digesting food. These particles of fat render the lymph milky in appearance, hence the name "lacteals" for the intestinal lymphatic radicles. This milky fluid is called *chyle*. The lymph proper and the chyle mingle in the thoracic duct to be poured into the venous system.

Lymph proper is a pale straw-colored fluid; after the admixture of chyle it is milky.

Pressure of lymph: The blood in the capillaries has been

stated as being under a pressure equal to 20–50 mm. of mercury. In exuding through the capillary-walls the blood loses about one-half its pressure; hence we find that the lymph in the tissue-spaces is under a pressure of 10–25 mm. of mercury. At the veins of the neck the lymph is under very low pressure, or is at zero, or even under a negative pressure due to the suction of the chest.

Factors producing lymph-flow; In some of the lower animals there is a distinct separate lymph-heart, the purpose of which is to act as a force-pump to drive on the lymph, just as the human heart drives on the blood. In man there is no such lymph-heart, but the flow of lymph depends on other causes. They are as follows:

(1) The *positive pressure* (10–25 mm. of mercury) in the lymph-spaces, as opposed to the zero or negative pressure at the other end of the lymph-channel, drives the lymph on.

(2) The *muscular movements* of the body compressing the lymphatics force the lymph on in the proper direction, the reverse flow being prevented by the valves. The chyle is aided in its flow by the actions of the muscular fibres of the small intestine, and possibly by the layer of unstriped muscle-fibre found in each intestinal villus. In the small intestine of the mouse the chyle has been seen to flow with intermittent movements, corresponding to the peristaltic movements. The contractility of the walls of the lymph-vessels themselves, due to the muscle-fibres they contain, probably supplies some of the force.

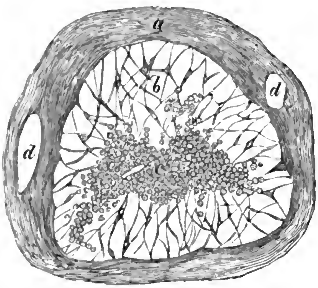
(3) The *thoracic aspiration* of the chest on inspiration sucks on the lymph in the same manner as it does the venous blood.

Lymph-ganglia: The lymph-ganglia, or *lymph-nodes*, are innumerable small masses, varying in size from 1 mm. to 2 cm. in diameter, interposed in the course of the lymphatics. They are found in great numbers in the neck, thorax, axilla, groin, and mesentery, and along the great vessels of the abdomen. A few are found in the popliteal space and in the arm as far as the elbow, but none further down the leg or forearm.

The lymph-ganglia consist of a mass of cellular pulp-sub-

stance, through which run many open channels, the whole being enclosed in a capsule. If a particular lymph-vessel be examined, it will be seen to empty directly at some point into a lymph-ganglion. The lymph flows through the open channels in the substance of the ganglion and emerges on the opposite side, to be again collected into a lymph-vessel, and so on to its destination (Fig. 38).

FIG. 38.



Simple lymphatic gland. *a*, the capsule, with sections of lymphatics, *d*, *d*, coursing through it; *b*, lacunar and intercommunicating passages, permeated by the lymph, and forming the superficial lymph-paths of Frey; *c*, nucleus or medullary portion of the gland, in the centre of which the section of a bloodvessel may be seen. The path pursued by the lymph through the medullary portion constitutes the deep or secondary lymph-path of Frey (Carpenter).

A lymph-ganglion is comparable to a sponge placed in a snug-fitting rubber bag. The rubber bag connects on one side with a rubber tube representing the afferent lymph-vessel, and from the opposite side there leads away from the rubber bag another tube representing the efferent lymph-vessel. The rubber bag is the representative of the capsule of the ganglion, the meshwork of the sponge is comparable to the framework of the ganglion, and the holes in the sponge to the open channels. The substance of a lymphatic ganglion is *adenoid tissue.*

Purpose of lymphatic ganglia: The lymphatic ganglia serve as filters for the lymph. Also the cell-division of leukocytes occurs in their channels. An important attribute is the way in which they serve to retard the spread of infection through the body, thus acting as safety-valves. If any portion of the body is infected, the poison is carried by the lymphatics to their especial glands. There its course is stopped till the opposition of the glands is overcome, when it proceeds to the next ones. As a result of this we get at first enlargement of the glands; later, if the process continues, they break down and are destroyed. If it were not for their action in this way, an infected wound might often

prove rapidly fatal before surgical treatment had time to be of value.

RESPIRATION.

By the **respiratory act** we mean the process by which oxygen is introduced into the system and by which carbonic oxide is excreted. This function is performed by the lungs, and the transfer is effected by the agency of the blood.

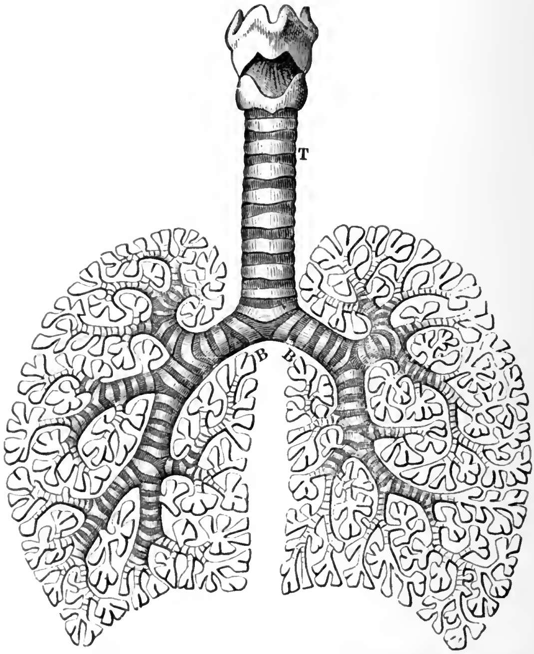
The respiratory act is subdivided into (1) the "*movements of respiration*," by which term is meant those movements that cause the thorax alternately to expand and collapse, thus filling and emptying the lungs of air; and (2) "*respiration*," used to designate the interchange of oxygen and carbon dioxide between the blood and the air in the lungs (external respiration); also the exchange of oxygen and carbon dioxide between the blood and the tissues of the body (internal respiration).

Movements of respiration: The action by which the lungs are filled with air (inspiration) is as follows: The thoracic cavity is expanded by muscular action; this expansion draws on the walls of the lungs through the intervention of the pleuræ, thus enlarging the cavity of the lungs. To prevent a vacuum in the lungs, air is taken through the nose or mouth, and passes through the pharynx to the larynx; entering the rima glottidis, it passes through the larynx to the trachea and bronchi. The air is somewhat warmed and moistened in its passage. The trachea and bronchi are lined with ciliated epithelium, which serves to sweep particles of dust and the like out of the air-passages. After the lungs have been filled with air the thoracic wall is made to collapse and the air is expelled from the lungs.

The respiratory tract: In all vertebrates and in many invertebrates certain specialized structures, either lungs or gills, are specially adapted for allowing the blood to come into close proximity with the air or water which contains air. A lung or gill in its simplest form consists of a thin membrane, on one side of which is a network of thin-walled bloodvessels, while the other side is in contact with the air or water. There is a difference of degree only between the most com-

plex and the simplest forms. In man the respiratory tract is highly complex, and includes essentially the *larynx, trachea, bronchi*, and *lungs* (Fig. 39).

FIG. 39.



Human larynx, trachea, bronchi, and lungs; showing the ramification of the bronchi and the division of the lungs into lobules (Dalton).

The larynx : The air enters the body through the mouth or nares. It first passes through the larynx, the upper part of the respiratory passage. This is a short tube, triangular on section, formed of hyaline cartilage, which contains the vocal cords. At its lower extremity the larynx joins the trachea.

The trachea : The trachea, or windpipe, is a hollow tube, four to four and a half inches long, composed of fibro-elas-

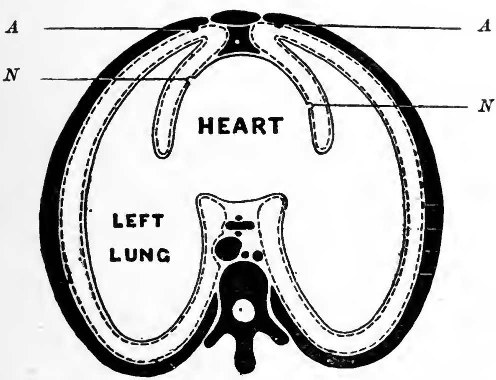
tic membrane, in which are enclosed a series of from sixteen to twenty cartilaginous rings. These latter serve to stiffen it. At its lower extremity it divides into two bronchi, one for each lung, named respectively the right and the left.

The bronchi: These are merely smaller editions of the trachea and of a similar structure. They divide, enter the substance of the lungs, and, subdividing, penetrate every part till they end in the lobules. As they get smaller the walls become thinner and the cartilaginous rings disappear.

The lungs: These occupy the larger part of the thorax. They are of a spongy, elastic texture, and on section appear to be solid organs for the greater part. In reality they are hollow. The lungs are two in number, the right and the left, of which the former is partially subdivided into three lobes ; the latter into two.

Covering each lung separately is a serous membrane, the **pleura**, which in the form of a sac envelops the outer sur-

Fig. 40.



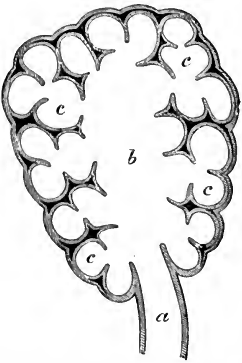
Diagrammatic view of the pleural sacs with the heart and lungs interposed. *A*, internal mammary artery ; *N*, phrenic nerve.

face of the lung and the inner surface of the chest-wall. The pericardium containing the heart is interposed between the two lungs (Fig. 40).

Minute anatomy of the lung: Each lobe of the lung is

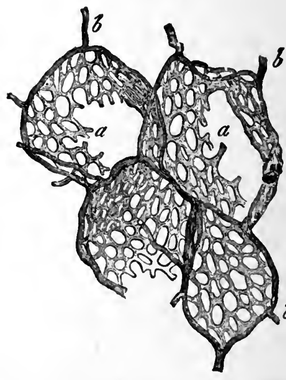
composed of numerous lobules, into each of which a small bronchiole enters, and the minute terminal branches of these bronchioles (*infundibula*) widen into a sort of irregular funnel having pouched or sacculated dilatations, known as *air-cells.* These air-cells are supported by numerous elastic fibres, and are lined with a very thin layer of flat (not ciliated) epithelium. Outside the epithelial lining is a very close mesh of capillaries, which are often exposed to air on both sides by lying in a partition between two of the air-cells. The air-cells or vesicles are about one-sixtieth of an inch in diameter, and the space between the capillaries is often less than the diameter of a capillary (Figs. 41 and 42). The total surface in the lungs bathed by the air is about two hundred square metres.

FIG. 41.



Single lobule of human lung. *a*, ultimate bronchial tube; *b*, cavity of lobule; *c*, *c*, *c*, pulmonary cells, or vesicles (Dalton).

FIG. 42.

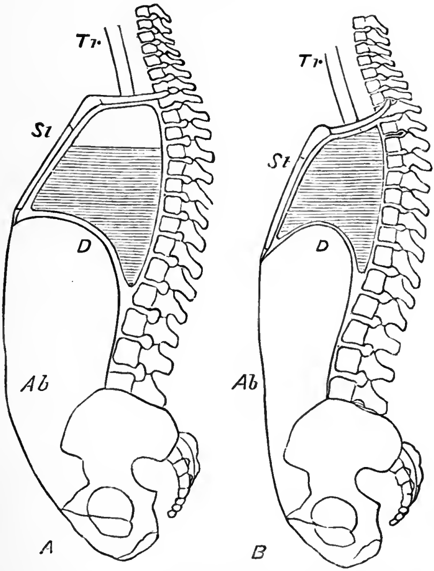


Network of capillary blood-vessels in the pulmonary vesicles of the horse. *a*, cavity of vesicle, with capillary plexus; *b*, pulmonary blood-vessels, supplying capillary plexus (Frey).

Muscles of inspiration: During quiet inspiration the cavity of the chest is increased in all three diameters—vertical, antero-posterior, and lateral. The upper part of the thoracic basket being fixed, the vertical diameter is increased by the descent of the diaphragm in contracting (Fig. 43). The external intercostals, together with other muscles, act on the

ribs so that they turn on their axes, with the result that the sternal ends are raised up and carried forward; at the same time the peculiar curve that exists in the rib at its angle

Fig. 43.



Diagrammatic sections of the body in inspiration and expiration. *A*, inspiration; *B*, expiration; *Tr*, trachea; *St*, sternum; *D*, diaphragm; *Ab*, abdominal walls. The shading roughly indicates the stationary air (Huxley).

causes an eversion of the lateral aspect of the rib when the sternal end is brought upward and forward. This eversion increases the lateral diameter.

The *axis of a rib* is a line running through the centre of the head (vertebral end) of the rib and through the articulation of the rib with the transverse process of the vertebra.

The muscles producing these changes in the diameters of the chest are the muscles of "quiet inspiration," and are as follows:

Diaphragm increases the vertical diameter;

Scaleni fix upper part of the thorax;

External intercostals and Interchondrals } draw the ribs upward;

Serrati postici superiores { fix the second rib and raise the third, fourth, and fifth ribs;

Levatores costarum breves raise the upper ten ribs.

It is stated that of the two types of respiration, "thoracic" and "abdominal," the former is more marked in women and the latter in men. This is true in the sense that women increase the antero-posterior and the lateral diameter of the chest more than do men, owing to the functional differences between the sexes, and also due to habits of dress, etc. On

Fig. 44.

The changes of the thoracic and abdominal walls of the male during respiration.

Fig. 45.

The same in the female (Hutchinson).

the other hand, adult males and children of both sexes use the diaphragm almost exclusively in quiet inspiration (Figs. 44 and 45).

During **forced inspiration** additional muscles are brought into play to permit of a more powerful inspiratory act. Beside the muscles already enumerated, the muscles of forced inspiration are as follows:

Trapezei and rhomboidei fix the shoulders;

Pectorales majores and minores, acting from the fixed shoulders, draw the sternum and ribs upward;

Sterno-mastoidei fix the upper part of the chest;

Erector spinæ stiffen the vertebral column;

Serrati postici inferiores, Quadrati lumborum, Sacro-lumbales,	draw the lower ribs downward and backward.

Muscles of expiration: At the close of inspiration the various muscles that raised the thorax relax, and by its own weight the thorax drops, thus compressing the lungs and expelling the air. In addition there is an active collapse of the lungs due to the recoil of the elastic tissue in the substance of the lung, the elastic fibres having been put on the stretch during inspiration. Also during inspiration the interosseous portions of the internal intercostal muscles were put upon the stretch; when expiration begins these muscles contract, but their contraction is not sufficiently forcible to pull the ribs down, and the only purpose of this contraction seems to be to keep the intercostal tissues tense and thus prevent bulging of the intercostal spaces.

Also during inspiration each costal cartilage was twisted in the direction of its long axis, due to the eversion of the rib twisting the rib-end of the cartilage, the sternal end being fixed. During expiration the costal cartilage tends to untwist itself. So we may justly say there are no muscles for *quiet expiration*, as the act is performed by the weight of the thorax, elastic recoil of the lungs, and untwisting of the cartilage.

Forced expiration is accomplished by the intervention of many muscles as follows:

Interosseous internal intercostals act forcibly in drawing down the ribs, when the lower part of the thorax is fixed;

Abdominal muscles fix the lower part of the thorax and press the abdominal contents upward;

Levatores ani and perineal muscles, hold the floor of the pelvis rigid against abdominal pressure.

Triangularis sterni draws the costal cartilages down.

Frequency of respiration: In normal adult life, with the body in repose, there are about eighteen respiratory cycles to the minute. Inspiration and expiration alternate without any appreciable pause between the two. The inspiration is somewhat shorter than the expiration; the ratio being about 5 to 6. In infants and invalids the rate is often much more rapid. The ratio to the pulse-rate is about 1 to 4 in the healthy individual. During violent activity both the respiratory- and pulse-rates increase, but the ratio remains about the same.

Respiratory sounds: When the ear is placed in contact with the chest-wall, or a stethoscope is used, a *respiratory murmur* will be heard, fairly marked during inspiration; short and faint during expiration, in a healthy subject. It varies in different parts of the chest-wall, being loudest over the large bronchi. The changes in these murmurs incident to disease of the respiratory tract are just as characteristic of the different pathological processes as are changes in the heart-sounds depending on disease of the heart; and it is upon the recognition of these changes that the value of auscultation depends.

Associated respiratory movements: With every inspiration (especially if rapid) there is dilatation of the nostrils; and a partial closure during expiration. The rima glottidis is in the same way opened for the ingress of air. This is like the respiratory act, in that the opening is a muscular act during inspiration, and the recoil, elastic, in ordinary breathing.

Capacity of the lungs: The lungs, if filled to their utmost, can hold about 4500 c.c. of air. This total of air is divided as follows: (1) tidal air, (2) reserve air, (3) residual air, and (4) complementary air.

Tidal air is the ordinary amount of air that passes in and out during each quiet respiration. It seldom goes lower than the large bronchi. Its amount is 500 c.c.

Reserve air is the amount of air in addition to the tidal air one can expel from the lungs in a forced expiration. It is ordinarily lodged in the bronchi and bronchioles. Its amount is 1600 c.c.

Residual air is found in the alveoli of the lungs, and remains even after the most violent expirations. Amount, 800 c.c.

Complementary air is the air taken in, in addition to the tidal air, in the most forced inspiration. Amount, 1600 c.c.

The complementary, tidal, and reserve airs have been called the *vital capacity* of the lungs.

Force of the inspiratory and expiratory muscles: The force of the inspiratory muscles is greatest in people of about five feet seven and a half inches in height, being equivalent, on the average, to a column of mercury three inches high. It diminishes in people above and below this height. The force of expiration is about one-third greater; but the variations are not so regular, as there are many variations due to the fact that the expiratory muscles are used for other purposes, hence becoming stronger.

Composition of inspired air: Pure air has a nearly uniform composition:

	By volume.	By weight.
Nitrogen, ...	79 parts	75 parts
Oxygen, ...	21 "	25 "
Carbonic acid, ...	.04 part	
Ammonia and impurities, trace.		

Expired air: After its sojourn in the lungs there are marked changes in the respired air. Its temperature is changed to nearly that of the body, regardless of the temperature of the atmosphere. The oxygen is decreased, carbon dioxide and aqueous vapor are increased; also there are present many minute particles of volatile organic bodies. Nitrogen is unchanged. The *composition* of expired air is about as follows:

	By volume.
Nitrogen, ...	79 parts
Oxygen, ...	16 "
Carbon dioxide, ...	4 "

Water increased (from 6 to 30 ounces per day).
Volatile organic bodies are added.

The *total weight* of expired air is somewhat heavier than

that of inspired air, because the amount of carbon dioxide gained weighs more than the amount of oxygen lost.

In temperate atmospheres the volume of expired air is greater than that of the inspired air, because the air has been expanded by being heated. If, however, the expired air be reduced to the temperature of that inspired, the volume of expired air will be found less than that inspired, as the carbon dioxide gained is less bulky than the oxygen lost.

Value of nitrogen: The nitrogen in the atmosphere serves merely as a diluent; pure oxygen would be too powerful to serve for respiration. We do find a little nitrogen in solution in the blood-plasma, but it probably serves no purpose in the body economy.

External respiration: By external respiration is meant the interchange of gases in the respired air and the gases of the blood while in the pulmonary capillaries. It is true the ordinary tidal air of respiration, lodged as it is in the upper air-passages, does not come into actual contact with the pulmonary capillaries, but by virtue of the physical laws of *diffusion of gases* the oxygen in the tidal air is diffused into the reserve air, and carbon dioxide and other wastes of the reserve air are diffused into the tidal air. A similar exchange takes place between the reserve air and the residual air. Thus it comes about that the residual air, while never leaving the air-cells of the lungs, is constantly revivified with fresh oxygen and constantly gets rid of its carbon dioxide and other impurities. The blood coming to the pulmonary capillaries through the pulmonary arteries is rich in carbon dioxide and other wastes, but poor in oxygen; on the other hand, the air in the alveoli is rich in oxygen, but poor in carbon dioxide. Hence the oxygen in the air is under high tension as compared with the oxygen in the blood; and likewise the carbon dioxide of the blood is under higher tension than the carbon dioxide of the air. Owing to these differences in pressures, interchanges of the gases readily take place, so as to equalize the pressures.

In the blood oxygen is in loose chemical combination with the hæmoglobin (oxyhæmoglobin). The amount of oxygen in the residual air of the pulmonary alveoli is estimated at

about 10 per cent., that of expired air being 16 per cent. It is found that unless there is present about 4 per cent. of oxygen there is no tendency for the blood of the pulmonary arteries (venous) to take up fresh oxygen; or, the *tension* of the oxygen in the reduced hæmoglobin of venous blood is about 4 per cent., and unless the oxygen-tension in the lungs is greater there is no absorption of oxygen. But, as we have seen, the amount of oxygen amounts to at least 10 per cent., and therefore the excess is sufficient to exceed the demands, and the exchange is readily made by diffusion through the thin capillary walls of the alveoli. On the other hand, the *tension* of the carbonic acid in the pulmonary arteries is much higher than in the alveoli, and hence the extrusion of this gas by diffusion is accomplished.

The following **changes in the blood** are noted after passing through the pulmonary capillaries: (1) Color, deep purple to bright scarlet by oxidization of the reduced hæmoglobin—*i. e.*, from venous becoming arterial blood; (2) gains oxygen; (3) loses carbonic acid; (4) becomes cooler; (5) coagulates more readily.

Internal respiration: Internal respiration means the exchange of gases between the arterial blood and the tissues of the body. This interchange takes place through the walls of the systemic capillaries, and depends on the same physical laws (differences in pressure) as already described for the pulmonary exchange.

The arterial blood, rich in oxygen, gives oxygen to the needy tissues, and in return relieves the tissues of their burden of carbon dioxide and other wastes. In the systemic capillaries the blood changes from arterial to venous.

Nervous mechanism of respiration: Respiration is described as one of the so-called automatic acts, but is profoundly modified by the reflexes and partially controlled by the will.

Throughout our lives we continue to breathe unconscious of the fact, unless our attention is called to it. A dash of cold water on the skin or a disagreeable mental or visual picture will produce an uncontrollable gasp; these are examples of *reflex influences* on respiration. One may so exert will as to increase or decrease the rate of respiration, but only up to

certain limits. It is impossible to commit suicide by "holding the breath."

Centres for respiration: In the medulla oblongata are centres for each half of the body, from which arise automatically the rhythmical impulses for the *inspiratory acts*. These so-called *automatic impulses* are generated by the presence or absence of oxygen in the blood (not presence of carbon dioxide) bathing the medulla. If the blood in the medulla is rich in oxygen, there is no impulse for an inspiratory act; but as soon as the oxygen is diminished to a given point the respiratory centre is stimulated to make an inspiratory effort. The *nerves* which convey to the muscles of inspiration their impulse are the phrenics (to the diaphragm) and the intercostals (to the intercostal muscles). In addition to the automatic impulses *from* the centres, there are certain regular reflex impulses (other than the unusual ones mentioned above—cutaneous reflexes, etc.) that are conveyed *to* the centres by the *pneumogastric nerves*.

The *pneumogastric nerves* arising in the medulla send branches to the lungs that terminate in filaments distributed to the walls of the air-cells. These fibres are afferent, and are stimulated by two factors: (1) The *lack of oxygen* in the air of the alveoli after expiration; (2) During the partial collapse of the lung at the end of expiration these filaments are *mechanically pinched* by the walls of the air-cells.

The stimuli thus generated in the terminal filaments of the pulmonary branches of the pneumogastric nerves convey their impulses to the centres of respiration, producing an additional impulse for inspiration.

The condition (amount of oxygen) of the blood bathing the respiratory centre is, however, the prime factor, the afferent impulses of the pneumogastrics being only secondary.

While there are distinct *expiratory centres* in the medulla for expiration, they act to produce forced expiration only when properly stimulated by afferent nerves—as, for example, if the superior laryngeal nerve be stimulated, the result is a forced explosive expiration, or cough.

Under *ordinary circumstances* when the inspiratory act is accomplished, the condition of the blood no longer calls for

more oxygen, and, the inspiratory impulse ceasing, the muscles of inspiration relax and expiration is a purely passive act.

In *dyspnœa*, however, the expiratory centres are stimulated.

Synchronism of respiratory centres: Although there is a respiratory centre for each half of the body, nevertheless, owing to their association-fibres, the two centres work synchronously. By making a median section of the medulla, the centres are disassociated, so that, if proper artificial stimuli be applied, one half of the chest may be made to inspire, while the other half expires.

Lack of oxygen in the blood: If the need be only moderate, there will be increased effort of both expiration and inspiration, and the respirations will be rapid—a condition known as *hyperpnœa*. As the oxygen becomes less and less abundant the symptoms become more severe, and the condition is known as *dyspnœa*. The dyspnœa increasing, the respiratory efforts become very violent, and the condition of *asphyxia* is seen. In this the face is blue, eyes staring, face anxious, and respirations very rapid and strident. Then follows a convulsive condition which is brief, the convulsions being very violent and involving the whole body. After this the patient lapses into a state of exhaustion, in which the respirations are slow and very feeble, and the general condition is one of collapse. Death ensues very soon.

Apnœa is absence of breathing.

Section of vagi: If one pneumogastric nerve be divided below the offshoot of the inferior laryngeal nerve, there is a temporary excitation of the respiratory rate, due to the mechanical stimulus of cutting; but soon the respirations return to normal, the other vagus taking up the work of both.

If both vagi be divided below the inferior laryngeal nerve, there is an excitation of respiration due to the stimulus of cutting, soon followed by slower and deeper inspirations and active expirations. *Stimulation of the central ends* of cut vagi will bring the rate and character back to the normal.

If the *superior laryngeals be divided*, a cough or expiratory sniff follows the act of cutting; later on the subject dies of

"foreign-body pneumonia," because the sensation of the larynx being lost foreign particles pass the larynx without being coughed out, enter the lungs, and give rise to a fatal pneumonia.

Section of the inferior laryngeals gives the same result; for although sensations in the larynx are present if the superior laryngeals are intact, all motion in the larynx is lost and coughing is ineffectual.

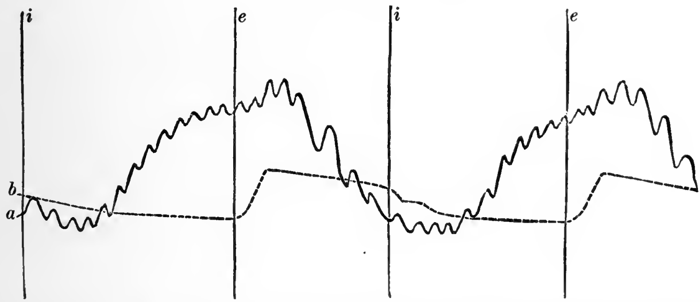
Vitiated atmosphere: In ill-ventilated rooms the air of the room is used repeatedly, and, besides becoming partially deprived of its oxygen, is charged with carbonic acid and with putrescible nitrogenous organic matters. This gives rise to an atmosphere which is intolerable to one who enters from fresh air. That such a condition is unsanitary needs no argument. The mere presence of the excess of carbonic acid is not in itself injurious; but the amount of carbon dioxide is indicative of the amount of organic matter present, and it is the latter that are highly poisonous. It is generally accepted as a fact that about 1000 cubic feet of air-space per head must be allowed in sleeping-quarters, and sufficient facilities for exchange of air to allow complete change in each hour. This ventilation must be accomplished without exposure to draughts.

Effect of respiration on the circulation: As the heart and its great vessels are contained together with the lungs in the thorax, an air-tight cavity, there naturally results a certain alteration in pressure on the heart when the capacity of the thorax changes. Though the expansion of the lungs during inspiration tends to compensate for this increased capacity, it never does so fully, as part of the atmospheric pressure is expended in overcoming the elasticity of the lungs. Therefore, during inspiration the pressure on the heart becomes considerably less than the atmospheric pressure exerted on the bloodvessels outside of the thoracic cavity. This difference varies from 5 to 8 mm. of mercury during the pause, up to 25 or 30 mm. at the end of a deep inspiration. The result of this is to draw more blood through the veins into the heart during inspiration, and consequently to increase arterial tension. The relative values of intrathoracic press-

ure and arterial tension may be graphically expressed as in Fig. 46.

Special respiratory acts: There are a number of involuntary and voluntary special respiratory acts, largely reflex, which are dependent upon modifications of inspiration and

FIG. 46.



Comparison of blood-pressure curve with curve of intrathoracic pressure. To be read from left to right. *a* is the blood-pressure curve, with its respiratory undulations, the slower beats on the descent being very marked; *b* is the curve of intrathoracic pressure obtained by connecting one limb of a manometer with the pleural cavity. Inspiration begins at *i*, expiration at *e*. The intrathoracic pressure rises very rapidly after the cessation of the inspiratory effort, and then slowly falls as the air issues from the chest; at the beginning of the inspiratory effort the fall becomes more rapid (Foster).

expiration—*e. g.*, sighing, hiccough, cough, sneezing, speaking, singing, sniffing, sobbing, laughing, yawning.

Sighing: This results from a prolonged inspiration, the air passing noiselessly through the larynx and being rather suddenly expelled.

Hiccough: This resembles sighing, but the inspiration is sudden, due to spasmodic action of the diaphragm.

Cough: This results from a deep inspiration followed by a forced and sudden expiration, during which the glottis is momentarily closed by spasmodic action of the vocal cords.

Sneezing: In this case, following on a deep inspiration, by a sudden and forced expiration the air is directed through the nasal passages.

Speaking: In this case there is a voluntary expiration, and the vocal cords, being rendered tense by their muscles, vibrate as the air passes over them, producing sound.

Singing: This only varies from speaking in the differing tension and position of the vocal cords and the consequently different sounds produced.

Sniffing: This results from rapidly repeated but incomplete nasal inspirations.

Sobbing: This consists of a series of convulsive inspirations, during which the glottis is more or less closed.

Laughing: This results from a series of short and rapid expirations.

Yawning: This is an act of inspiration, more or less involuntary, accompanied by a stretching of various facial muscles.

Sucking: This is not really a respiratory act. It is caused chiefly by the depressor muscle of the os hyoides, which, by drawing down and back the floor of the mouth, produce a partial vacuum in it.

DIGESTION.

By **digestion** we indicate the process by which food is introduced into the body and prepared in such way that it becomes suitable for absorption and tissue-nutrition. The process may be divided logically and conveniently into mastication, insalivation, deglutition, stomach digestion, intestinal digestion, and defecation.

The mouth: The first portion of the alimentary tract is the mouth. In this is received the food destined to support the body. It is a cavity contained between the jaws and bounded laterally by the cheeks. Its roof is formed by the hard and soft palate, and its floor by the tongue. It is lined throughout with mucous membrane, which is provided with numerous mucous glands, and into it open the ducts of the salivary glands. The *tongue* is both a prehensile organ and also the chief seat of the sensation of taste. In this cavity occurs the process of mastication.

Mastication: When a mass of food enters the mouth it is caught by the tongue and moved to a position such that it may be crushed and ground between the upper and lower teeth. This process is favored by the action of the tongue and of the cheeks, which not only crush the softer food-

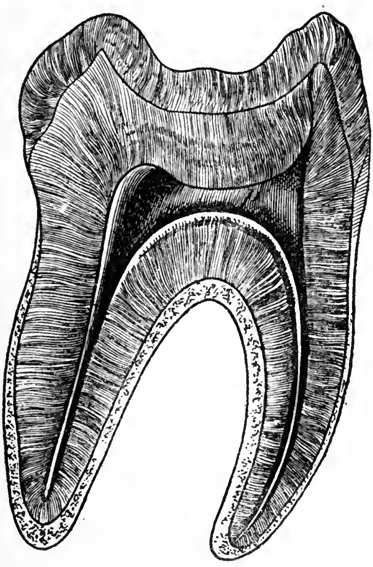
masses, but bring the less tractable portions repeatedly under the action of the teeth.

There are during life two **sets of teeth**, *temporary* and *permanent*. In the first set are twenty teeth, and in the second thirty-two. The *permanent set* are arranged as follows:

	Molar.	Bicuspid.	Canine.	Incisor.	Canine.	Bicuspid.	Molar.
Upper.	3	2	1	4	1	2	3
Lower.	3	2	1	4	1	2	3

A **tooth** may be roughly described as consisting of a *crown*, *neck*, and *fang* or *fangs*. The crown is the portion which projects above the margin of the gum; the neck is the constricted part below the crown which is covered by the free

FIG. 47.



Section of human molar tooth, magnified (Owen).

edges of the gum; while the fang or root includes all below this. On making a section of a tooth, for instance a molar (Fig. 47), it will be seen that there is a cavity within the

crown which extends into and through the fangs, opening by a small aperture at their apices. This is the *pulp-cavity,* and contains in the living tooth the *pulp.* A portion of the tooth-structure resembles bone, anatomically as well as chemically. The *crusta petrosa,* or *cement,* is true bone, and covers in the *dentine* of the *fang,* while outside the *dentine* of the *crown* is a very dense layer of *enamel* (of epithelial origin).

Muscles of mastication: Biting movements are produced by the action of the temporal, masseter, and internal pterygoid muscles, opposing the depressors of the jaw; grinding movements are produced by the alternate action of the external pterygoids. The action is to some extent reflex, though largely voluntary, and is controlled in the medulla through branches of the cranial nerves, motor impulses coming through branches of the trigeminus and (to the tongue) hypoglossal nerves.

Insalivation: The mixing and thorough moistening of the food-mass with the saliva and mucus in the mouth during the act of chewing are called insalivation.

Saliva: The saliva is derived almost entirely from the parotid, submaxillary, and sublingual glands, and is secreted most abundantly during the mastication of food. Of the glands, the parotid secretes pure saliva containing ptyalin; the sublingual secretes only mucus; while the submaxillary is a mixed gland, secreting both saliva and mucus. The resultant mixture of the secretions of these and the other glands of the mucous membrane constitutes what is ordinarily known as saliva, though really it should be called *mixed saliva.* It is a transparent watery fluid, and is somewhat viscid from the mixture of mucus. This viscidity allows it to retain air-bubbles when churned by the action of the tongue and cheeks. It has a specific gravity of about 1006 and an alkaline reaction. Chemically, it is mostly ($99\frac{1}{2}$ per cent.) water, holding in solution very small amounts of salts and proteids, with the addition of a ferment called ptyalin. The amount secreted in twenty-four hours is estimated to be one to two quarts; most abundant secretion occurring during mastication.

It keeps the mouth in a moist condition, and so lubricates the tongue in speaking and in chewing; dissolves the soluble portions of the food, and in this way brings them in contact

with the organs of taste; mixes with the food, and forms a soft and slippery bolus suitable for swallowing. Saliva from the front of the mouth, containing more water, softens the bolus, while the tonsillar and pharyngeal secretions, being mucous, coat it with a slippery surface. The saliva has a special digestive function by the action of its ferment, ptyalin.

Ptyalin: Ptyalin is a ferment (a non-nitrogenous body having an uncertain chemical composition), with the special property of converting cooked starch into maltose. While the ferment itself cannot be isolated and analyzed, a glycerin solution may be obtained from the parotid and submaxillary glands, which have been dehydrated by alcohol. This ferment does not act upon any other body than starch. The action of the ferment in changing starch to sugar is known as an amylolytic action, and such a ferment is called an amylolytic ferment. The kind of sugar resulting from the action of ptyalin is maltose.

Ptyalin works most actively at a temperature of 40° C. and in a neutral solution. Its action is suspended in an acid solution, but continues in a slightly alkaline medium. At 0° C. its action is suspended, and if raised to 65° C. is destroyed. Most of the ptyalin (in man) is found in the saliva secreted by the parotid glands. The sublingual glands secrete very little ptyalin (if any), the submaxillary glands being midway between the other two in the amount of ptyalin formed.

The salivary glands do not become active until the subject is from four to six months old; hence the reason for avoiding starchy food for young infants.

Nerve-control of salivary secretion: Saliva is secreted more abundantly upon the application of a stimulus. It is therefore increased by reflex nerve-force. The stimuli may be mechanical or chemical or mental; thus the flow of saliva is increased by taking food into the mouth or by irritating the inside of the mouth by scratching or burning, or by looking at or smelling or even thinking about food.

In the submaxillary gland the chorda tympani nerve is said to have a double function—to increase the vascularity of the gland by one portion of its fibres, and to excite the secreting function by another set of fibres, the sympathetic nerves of the gland acting as the vaso-constrictors.

In the parotid the vaso-dilator impulse comes also from the facial nerve through the fifth by the communication of the lesser petrosal nerve. The vaso-constrictor impulse comes from the sympathetic.

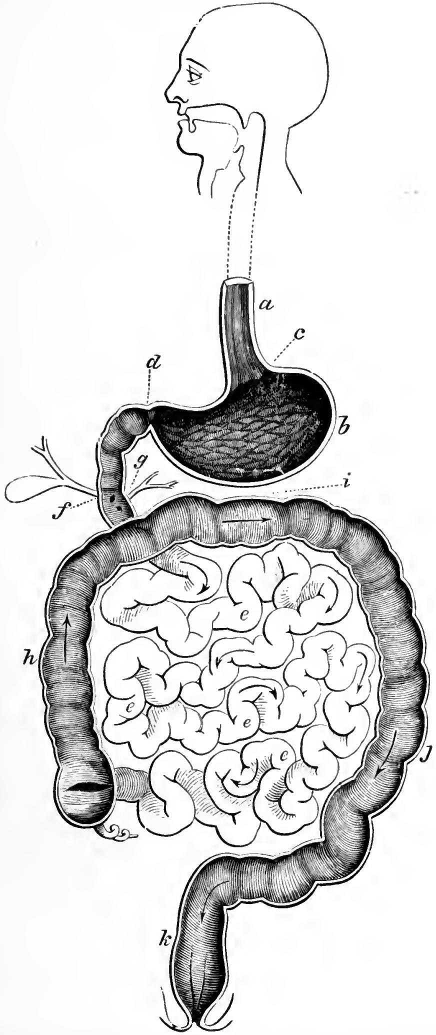
There is found a medullary centre which controls this function.

Deglutition: Deglutition, or swallowing, is the process by which we convey food from the mouth to the stomach, and may be divided for the purpose of analysis into three actions: 1st. The food after mastication is pushed by the tongue against the palate, and so forced on toward the fauces. (The importance of the tongue should be remembered by the surgeon when operating on it. Enough of the base must be left to press against the palate, otherwise deglutition will become very difficult or impossible.) 2d. As soon as the bolus enters the pharynx it is pushed on by the tongue and by the contraction of the pillars of the fauces and the constrictors of the pharynx toward the œsophageal opening. The pharyngeal vault is guarded from invasion by solid or liquid food by the valve-action of the soft palate, while the opening of the glottis is protected by the simultaneous intrinsic muscular closure of the rima glottidis and by the partial covering of the epiglottis. When the muscles of the fauces and tongue push on the food-mass, they also draw up the larynx and dilate the œsophageal opening. 3d. The œsophagus grasps the food, and a peristaltic wave-series carries it rapidly on to the cardiac opening of the stomach. The time involved in the whole act of deglutition is about six seconds. The beginning (1st) of the act of swallowing is voluntary, the remainder reflex, and is governed by centres in the medulla oblongata acting through the cranial nerves which supply the parts. The trigeminus, glosso-pharyngeus, and vagus by their sensory and motor functions act both in the capacity of afferent and efferent communication with the medullary centre.

The Stomach.

Structure: The stomach (Fig. 48) is an organ which resembles in structure the rest of the intestinal tract; it is

FIG. 48.

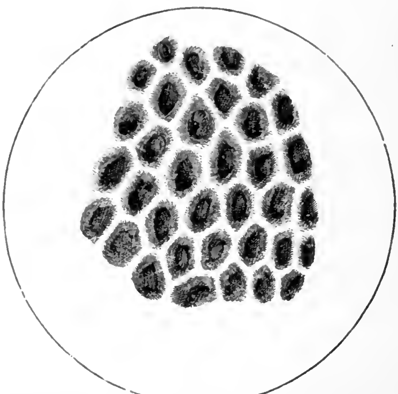


Human alimentary canal. *a*, œsophagus; *b*, stomach; *c*, cardiac orifice; *d*, pylorus; *e*, small intestine; *f*, biliary duct; *g*, pancreatic duct; *h*, ascending colon; *i*, transverse colon; *j*, descending colon; *k*, rectum.

hollow, having a peritoneal covering and a mucous membrane lining, with a muscular layer between. It is in this mucous membrane that the special function of the stomach lies, for here are found glands which secrete the gastric juice. The active peristaltic motion churns the food about after deglutition, and exposes it thoroughly to the action of the digestive agents. The function of the stomach is the digestion of proteids. When distended it measures about fifteen inches from end to end, and about five inches antero-posteriorly.

Glands of the stomach: If one looks closely at the mucous surface of the stomach, it is seen to present a sort of reticulated (Fig. 49) appearance, the meshes being larger at the

FIG. 49.



Free surface of the gastric mucous membrane, viewed from above, from pig's stomach; cardiac portion; moderately magnified.

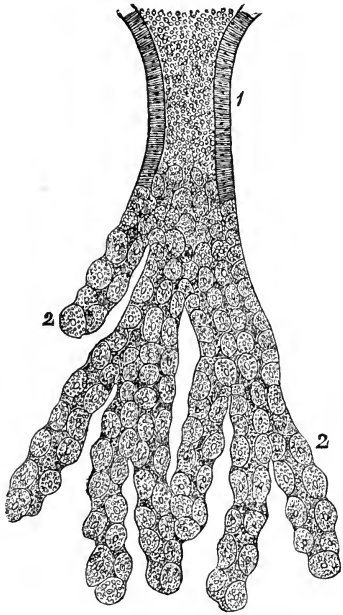
pyloric than at the cardiac end of the stomach. It is in the interstices of this mesh that the glands open. The openings are smaller at the cardiac than at the pyloric end, and the character of the glands changes: we therefore speak of two varieties of gastric glands—(1) peptic; (2) pyloric.

(1) The *peptic glands* are arranged in groups throughout the stomach, but not so abundantly at the pyloric end. They often consist of a simple tube dipping into the surface and lined with columnar epithelium (Fig. 50), but they may be

branched—*i. e.*, several glands may empty into a common duct. The columnar epithelium in the deeper portion of the gland contains large, almost globular, cells, which are known as peptic cells.

(2) The *pyloric glands*, or mucous glands, like the peptic, may be simple or compound. The ducts are larger, and the large cells are wanting (Fig. 51). During digestion the cells of both varieties of glands become swollen, and in them are found granules which are supposed to be pepsin, or that from which pepsin is formed.

Fig. 50.



Compound gastric follicle, from the cardiac portion of the human stomach. 1, excretory tubes leading to the surface; 2, tubular follicles containing spheroidal cells (Kölliker).

Gastric juice: When the stomach is not at work it contains no gastric juice, but is bathed in an alkaline mucus. As soon as food enters the organ, however, it immediately begins to secrete considerable quantities of an acid fluid, which soaks into and mingles with the food. The celebrated case of Alexis St. Martin, who had a gunshot-wound resulting in gastric fistula, enabled Beaumont, surgeon U. S. A., to investigate accurately its composition. It is a limpid, colorless fluid of specific gravity 1001–1010 and acid reaction. It contains about ½ per cent. solid matter. Its composition is nearly—

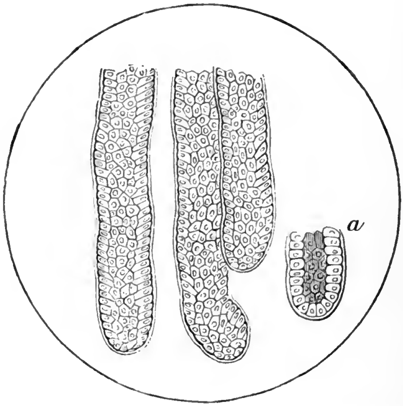
Water	99.50
Pepsin	.25
Hydrochloric acid	.05
Salts (alkaline chlorides and phosphates)	.20
	100.00

This composition is not constant, as the proportions vary considerably, HCl, for example, being present much more abundantly in some cases.

Secretion of gastric juice: The stomach secretes about fifteen pints of gastric juice per diem.

The *hydrochloric acid* is probably secreted by the cubical parietal cells of the peptic glands. Very little seems to be formed by the pyloric glands.

FIG. 51.



Tubular follicles, from pyloric portion of pig's stomach, showing their cæcal extremities and epithelial lining; at *a* is the torn end of a follicle, showing its cavity more highly magnified.

The *pepsin* comes from the globular cells in the peptic glands. These cells are supposed to form a substance called *pepsinogen*, from which pepsin is derived. Pepsin is derived for commercial or for experimental purposes from fresh stomachs by scraping the surface and dissolving out the ferment with cold water, or by mincing the mucous membrane and extracting the ferment with glycerin after dehydrating with alcohol.

Functions of the gastric juice: The principal function of the gastric juice is the transforming of proteids into peptones.

This action depends upon the presence of both pepsin and acid. The first change which occurs is the formation of acid albumin, but as the action of the ferment continues the acid albumin is transformed to peptone. The presence of acid albumin is demonstrated by the addition of an alkali, which precipitates it.

The action of the pepsin in converting proteids to peptones is called a *proteolytic* action, and chemically its action is to cause a hydration of the proteid molecules.

Milk is curdled in the stomach by a ferment, aside from pepsin, which is derived from the gastric juice. This action takes place in the absence of hydrochloric acid. Rennet (derived from the fourth stomach of calves) is used for this purpose in cheese manufacture.

Fats are unaffected, except that the albuminous capsules of fat-cells in adipose tissues are digested and the oil set free in globules.

Carbohydrates are unaffected.

In conclusion, therefore, it can be said that gastric digestion is of a *preparatory character*, fitting the food for further digestion in the intestines. Not only the carbohydrates and fats pass the stomach practically unchanged, but part of the proteids, the hemipeptones, are not completely digested. That it is not indispensable is proven by the fact that recently the entire stomach was removed from a woman, yet she showed no ill effects, but lived for a year or more, and finally died from another cause.

Characteristics of peptones: (1) They are diffusible—*i. e.*, have the property of osmosis, or passing through an animal membrane. This is of great importance in digestion, for if this property were absent no animal food could be absorbed from the intestines. (2) They are very freely soluble in water and neutral solutions. (3) They do not respond to the chemical tests for other proteid substances. They are not precipitated by heat and the mineral acids, but are precipitated by tannic and picric acids and by the bichloride of mercury.

Muscular action of the stomach: The stomach is elastic, and is supplied with circular and longitudinal muscles in its

middle coat. These muscular fibres are capable of producing peristaltic movements of the organ, which turn the food over and over during the process of digestion. This elastic pouch is closed at each end by strong, sphincter-like, circular bands of muscles at the cardiac and pyloric openings, and until the stomach digestion is well advanced none of the contents escapes; but as the peptone-making advances the pyloric opening permits the escape of the digested food, and this is aided by strong peristaltic efforts on the part of the stomach at its pyloric end. Toward the end of digestion the pylorus permits the escape of undigested as well as of digested matter. The circulation of the stomach-contents is circumferentially toward the pylorus, but centrally toward the cardiac opening.

The digested food as it leaves the stomach is called *chyme.*

Time required for digestion: The time varies with the kind and amount of food from one to five or six hours. Digestion is favored by rest of the stomach before eating, by gentle exercise of the mind or body, by an undisturbed mental condition, and by a healthy condition of the body.

Conditions favoring gastric digestion: The temperature of the body is most favorable, and the presence of acid—preferably HCl—is essential. For the best results the percentage of HCl should be about $\frac{1}{50}$th of 1 per cent. Excess of acid, or neutralization, will stop the process. The movements of the stomach assist digestion by thoroughly mixing the food and the gastric juice. Digestive secretion does not continue except during the presence of food. Also the removal of completed products assists in the conversion of the remainder.

Capacity of the stomach: About a quart in the adult, but its muscular walls enable it to contract so as to fit its contents if much or little. When empty the stomach is tightly contracted.

Nervous mechanism of gastric digestion: The pneumogastric and sympathetic (splanchnic from the solar plexus) are the nerves which supply the stomach, and besides these there are numerous ganglia in the stomach-walls. The ordinary

motion-stimulus of the organ lies in the intrinsic ganglia. Irritation of the pneumogastric nerve causes contraction; its division, cessation of peristalsis. But, further than this, the vagus has control to a considerable degree over secretion in the stomach.

Digestion of the stomach after death: When death occurs at a time when the stomach contains food and gastric digestion is going on the walls of the stomach are often partially digested, even to such an extent that a perforation occurs. This condition is often found in *post-mortems* on the human body. Many reasons have been brought forward as to why this does not occur during life, but no entirely satisfactory theory has yet been propounded. Some have thought that gastric ulcers were merely an example of localized self-digestion.

Vomiting: The regurgitation of food from the stomach through the cardiac orifice, and thence through the mouth, may occur when the cardiac opening is free and the pylorus is closed. This is usually a reflex act, and is performed by the contraction of the stomach, aided by the pressure of the abdominal muscles opposing the fixed diaphragm. It may be described as a reversed peristalsis. The stimuli which excite the reflex may be either local in the stomach or peripheral. Violent irritation of the gastric mucous membrane will excite it; also mental impulses, from ocular, auditory, or olfactory sources; injury or irritation of the testis, ovary, kidney, etc.; unusual motion, as swinging; certain diseases; and effort of will in some is sufficient. There is a vomiting-centre in the medulla acting through the pneumogastric nerve.

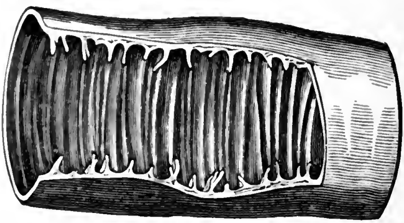
Absorption from the stomach: Although the stomach is not designed as an organ of absorption, nevertheless probably some water and peptones are absorbed by the capillaries of the stomach-wall.

Small Intestine.

Intestinal digestion: By the peristaltic action of the gut the food is carried on through the length of the organ, but its

progress is more or less impeded by the *valvulæ conniventes,* which are folds of the mucous membrane extending transversely across the intestine at right angles to its long axis, and occupying usually one-third or one-half of the circumference, but sometimes extending all the way around. They commence close to the stomach, and are well developed in the upper two-fifths of the small intestine. They then gradually diminish in size and number, and finally disappear at the commencement of the lower fourth. These folds of the mucous coat not only retard the too rapid advance of food, but cause it to be thoroughly exposed to the action of the digestive fluids (Fig. 52). Soon after passing the pylorus food

FIG. 52.



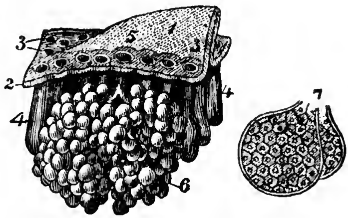
Portion of small intestine laid open to show valvulæ conniventes (Brinton).

comes in contact with the *alkaline secretions* of the small intestine and of the liver and pancreas. In the small intestine the food is still further *prepared* for *absorption,* and from this part of the alimentary tract the digested food is taken up for body-nutrition. The *peristaltic action* is controlled by the sympathetic system of nerves. Auerbach's plexus lies between the circular and longitudinal muscular coats. It is also known as the plexus mesentericus. The *blood-supply* is also controlled by the sympathetic system. Meissner's plexus lies beneath the mucous coat, and is regarded as the source of control of the blood-supply and of the function of absorption.

Glands of the small intestine: There are three types of glands peculiar to the small intestine: (1) Lieberkühn's, (2) Brunner's, and (3) Peyer's glands.

Glands of Lieberkühn: These glands (or follicles or crypts) are thickly distributed over the whole surface of the small and large intestine, being larger in the large intestine. They are simply tubular depressions in the mucous membrane, lined with columnar epithelium, which contains occasional large "goblet"-cells.

Fig. 53.



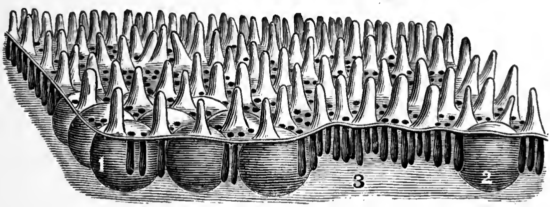
A vertical section of the duodenum highly magnified. 1, a fold-like villus; 2, epithelium of the mucous membrane; 3, orifices of the tubular glands; 4–5, orifice of a duodenal gland; 6–7, two vesicles of the latter, more highly magnified, exhibiting the epithelial cells lining their internal surface (Leidy).

Brunner's glands are found in the duodenum alone, and are situated in the submucous tissue. They resemble the pyloric glands of the stomach, and, like them, are usually compound glands. The duct of the gland passes up through the mucous membrane and opens at its surface (Fig. 53).

Peyer's glands: These are of two varieties—(1) solitary and (2) agminate.

(1) The solitary glands consist of a rounded mass of whitish adenoid tissue about $\frac{1}{25}$th to $\frac{1}{10}$th in. in diameter, situated in the submucous tissue, but often projecting to the surface of the intestine. Each lymphoid mass is surrounded by Lieberkühn's follicles (Fig. 54).

Fig. 54.



Portions of the mucous membrane from the ileum, moderately magnified, exhibiting the villi on its free surface, and between them the orifices of the tubular glands. 1, portion of an agminated gland; 2, a solitary gland; 3, fibrous tissue (Leidy).

(2) The agminate glands (Peyer's patches) consist of groups of these adenoid masses, making "patches" in the mucous membrane $\frac{1}{2}$ to 3 in. long and about $\frac{1}{2}$ in. wide.

Intestinal juice: The intestinal juice, or *succus entericus*, is the secretion of the intestinal glands. This secretion is yellow in color and is markedly alkaline. Its effect upon digestion is not fully understood, but it probably has some effect upon saccharose. However, its chief function seems to be to supply loss of fluid—*i. e.*, to take the place of that which is absorbed as digestion progresses. At any rate, the contents of the small intestine as they enter the colon are about as fluid as when they leave the stomach.

Other digestive secretions: The most important digestive fluids that act upon the food while in the intestines are not derived from the intestines, but are poured into the small intestine near its beginning. These secretions are two in number, and are formed respectively by the pancreas and the liver.

The Pancreas.

The **pancreas** is an organ lying in the upper part of the abdomen in contact with the duodenum: in length it is about six inches, and is thicker at its right or duodenal end. It is a conglomerate gland, resembling in structure the salivary glands. During digestion it is active, but is quiescent in the intervals. Its secretion, *pancreatic fluid*, is discharged into a main duct which receives branches from the lobes of the gland, and is emptied with the bile through a common opening about two or three inches beyond the pylorus. During digestion the cells of the organ become granular, and the granules are thought to consist of the substance from which the ferments of the pancreas are derived, *zymogen*, rather than of the ferments themselves.

Pancreatic juice: The pancreatic juice is a clear, colorless fluid, having an alkaline reaction and a notably viscid consistency. It coagulates with heat, and is made quite gelatinous by cold. Specific gravity, 1015. Its composition varies.

Composition of pancreatic juice:

Water	90
Organic matter:	
Ferments, Serum-albumin, Alkali-albumin, Fats, soaps, etc.,	9
Inorganic salts (chiefly sodium chloride)	1
	100

Pancreatic ferments: (1) *Trypsin*, a peptone-forming (proteolytic) ferment, which continues the digestion of proteids begun in the stomach. It forms a peptone which resembles the stomach peptone in its reactions. This ferment, unlike pepsin, only acts in an alkaline medium. It acts less vigorously upon gelatins and other nitrogenous bodies.

(2) *Amylopsin*, a starch-changing (amylolytic) ferment, by which starch is converted to maltose, as by the ptyalin in the saliva.

(3) *Steapsin*, a ferment by which fats are broken up from the large globules and emulsified or saponified in alkaline media. It is claimed by some that this is not a ferment-action, but is the result of the action of the alkaline intestinal contents upon the fat.

Of these processes the *emulsification*, or breaking the fat-globules into minute particles, is by far the more important, as it allows this form of food to be absorbed from the gut. Milk is an excellent example of a natural emulsion.

Saponification (or soap-making) results from the fatty acid combining with an alkali, forming the corresponding salt and glycerin—*e. g.*:

$$\underset{\text{Stearin}}{\left.\begin{matrix}(C_{18}H_{35}O)_3\\ C_3H_5\end{matrix}\right\}O_3} + \underset{\text{Potassium hydrate}}{3\left.\begin{matrix}H\\ K\end{matrix}\right\}O} = \underset{\text{Potassium stearate}}{3\left(\left.\begin{matrix}C_{18}H_{35}O\\ K\end{matrix}\right\}O\right)} + \underset{\text{Glycerin.}}{\left.\begin{matrix}C_3H_5\\ H_3\end{matrix}\right\}O_3}$$

Difference in action of trypsin and pepsin: These two ferments act on proteids in different ways. Under the influence of pepsin the proteid first swells, then gradually becomes softer, changes in color, and breaks down into a grumous

mass. When exposed to the action of trypsin, however, proteids do not swell up, but are eroded or eaten away, seeming at times as though they were full of worm-holes. Pepsin converts proteids into hemi-albumose and anti-albumose, which it later converts into hemipeptone and antipeptone. Trypsin splits the proteids at once into deutero-albumose, and also carries the process a step further than pepsin, splitting the hemipeptones into leucin and tyrosin.

Function of pancreatic juice: It is most active during digestion, and is peculiar in having an effect upon all forms of food which require preparation for absorption—upon proteids, starches, and fats.

Conditions favoring pancreatic digestion: Moderate heat (100° F.), an alkaline medium, and the removal of the products of the ferment-action as soon as the change is completed.

The Liver.

The **liver** is the largest gland in the body, and is situated in the upper part of the abdominal cavity. It secretes a fluid known as the *bile* or gall, which is stored in a bladder lying attached to its lower surface. The functions of the organ are: (1) secretion, (2) excretion, (3) glycogenic function, and (4) elaboration of urea.

Secretion of the liver: The secretion of the liver is stored in the *gall-bladder* until its flow is excited by the acid discharge of the stomach-contents into the duodenum. It is an active secretion, and not a passive filtration from the blood, for if a manometer-tube be fastened in the duct it will indicate a pressure greater than that of the blood. While the gall-bladder acts as a storage reservoir, the bile does not necessarily enter it, but may discharge directly from the hepatic into the common duct. The opening of the common duct into the duodenum is guarded by a sphincter-like arrangement of the muscular fibres in the gut-wall. The gall-bladder and the gall-duct are provided with unstriped muscular fibres, so that they may empty themselves. Inspiration and expiration bring alternating pressure upon the gall-bladder, and aid in emptying it.

Amount of bile: The quantity varies with the amount of food taken, but is estimated to vary between twenty and forty ounces, or, approximately, from a pint to a quart, in twenty-four hours.

Character of the bile: It is a viscid, almost ropy fluid, of a yellow or red or greenish color and bitter taste. It is faintly alkaline or neutral in reaction, and has a specific gravity of about 1020. Its composition is, approximately:

Water		86
Organic matter,	Bile salts, 9; Fat and cholesterin, 1; Mucus and pigments, 3	13
Inorganic salts		1
		100

Bile-salts: The bile-salts are sodium glycocholate (Fig. 55) and sodium taurocholate. They may be isolated in crys-

Fig. 55.

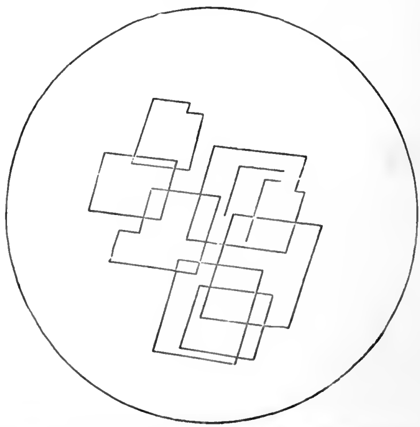
Sodium glycocholate from ox-bile, after two days' crystallization. At the lower part of the figure the crystals are melting into drops, from the evaporation of the ether and absorption of moisture (Dalton).

talline form from bile, and are present in human bile in about equal proportions. They are soluble and very deliquescent

colorless crystals, which have the bitter taste of bile. *Test by Pettenkofer's method:* add to a solution of bile a small amount of a solution of cane-sugar. On treating this solution with pure sulphuric acid drop by drop there is first a precipitation of a turbid sediment (cholic acid); this is cleared by a further addition of sulphuric acid, and the solution assumes a bright cherry color, changing to violet, and, if much bile be present, to deep purple.

Bile-pigments: The bile-pigments are biliverdin and bilirubin. Both pigments are found in human bile, but the former is characteristic of the bile of herbivora, and the latter, bilirubin, of the bile of carnivora. The pigments are

FIG. 56.



Cholesterin from the contents of an encysted tumor.

crystallizable, and are insoluble in water. The crystals have the green and red colors of the pigments. *Gmelin's bile test:* add fuming nitric (nitroso-nitric) acid, and there results a play of colors which is best seen when the bile solution is in thin layer on a white plate. The presence of the bile-pigments is shown also by absorption-bands in the spectrum. Bilirubin is derived from hæmoglobin, and biliverdin from the bilirubin, as they are chemically closely allied.

In considering the death of the red blood-corpuscle, it has been already stated in the chapter on the Blood that the hæmoglobin from the disintegrated red corpuscle is eliminated by the liver. This is the hæmoglobin that makes the bile-pigment.

Cholesterin is a crystallizable, insoluble substance which belongs to the alcohol group in chemical composition. Best recognized by microscopic appearance of the crystals (Fig. 56), though it may be tested chemically by the addition of sulphuric acid, which gives a red reaction.

Use of bile in digestion: (1) The alkaline reaction of the bile aids the pancreatic and checks the pepsin digestion; it aids in the emulsion of the fats, and is probably very active in this process. (2) It moistens the mucous membrane and favors the absorption of digested food. (3) It acts as a natural purgative and as a natural antiseptic, and in this way is very essential to the proper performance of the digestive process. As a purgative bile acts by stimulating peristalsis.

Excretion of the liver: The bile for the most part, in normal conditions, is a sort of circulating fluid: it is secreted by the liver, poured into the intestines, and reabsorbed from them, to be returned through the portal vein to the liver for recirculation. There is, however, a small proportion of biliary matter, about one-sixteenth, which is not absorbed, and this consists chiefly of the pigments of the bile. The salts are nearly all reabsorbed in the assimilation. Further than this, the liver is found, so to speak, to filter materials which would be poisonous if circulating in the general system, and either to reject them at once, or to store them up and return them slowly back to the intestine. The excrementitious material from the liver is known as *stercobilin.* Stercorin is found in the fæces, and is thought to be an excretion of the liver: it closely resembles cholesterin, and is supposed to be a modification of cholesterin by digestion. Whether or not the stercorin (cholesterin) is an excretion of the liver corresponding to the urea of the kidney is somewhat uncertain.

Glycogenic function of the liver: The liver normally forms a substance resembling starch in its chemical composition.

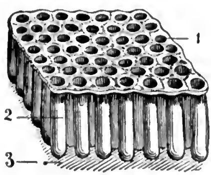
This is known as glycogen, and is formed from glucose taken up by the portal circulation. Its chemical formula is that of starch ($C_6H_{10}O_5$), and it is derived from glucose ($C_6H_{12}O_6$) by dehydration, and is rapidly changed by diastatic ferments to glucose. This process is known as the glycogenic function of the liver: its use is the storage of a fund of carbohydrate material (an "animal starch") to maintain a steady supply to the system.

Elaboration of urea: This subject will be discussed under the Urine.

Large Intestine.

Structure: While the villi and valvulæ are absent, yet throughout its whole extent there are found tubular and solitary glands which closely resemble those of the small intestine. The tubular glands, however, are more numerous, longer, and more closely set together (Fig. 57).

Fig. 57.



Section of the mucous membrane of the colon. 1, free surface exhibiting the orifices of the tubular glands; 2-3, fibrous tissue moderately magnified.

Digestion: The *chyme* which enters the large intestine still continues under the influence of the ferments, and the process of digestion continues. The food may undergo acid fermentation here, but there is no new digestive action. That the large intestine may have the power of acting upon food is shown by the absorption of fats, proteids, etc., which are taken in nutrient enemata.

Defecation: The expulsion of the refuse of digestion from the intestine is partly a voluntary act, but more especially reflex. The voluntary act is the pressure of the abdominal muscles upon the contained viscera, while the reflex is an increased peristalsis in the sigmoid flexure and rectum and the relaxation of the sphincter. The centre which governs this act, so far as it is reflex, lies in the lumbar region of the spinal cord.

ABSORPTION.

Absorption is the process by which the digested food is taken from the intestines and carried into the blood, whence it is taken to nourish the cells. The same term is applied to the removal of worn-out material from the tissues. Chyme is the name given to food after digestion. By digestion, the proteids, starches, and fats, which were not dialyzable, have become peptones, sugars, and emulsified fat. All these products of digestion are readily capable of dialysis, and therefore ready for absorption. The absorption takes place through the bloodvessels and lymphatics of the intestine.

By **dialysis** we mean the property of fluids which enables them to pass through animal membranes—osmosis. This we have seen is possessed in a high degree by the ingredients of chyle. The reverse process may occur, and fluids (serum) from the blood may similarly be drawn into the intestinal canal, as is seen when the salines are used as purgatives.

Too much importance must not, however, be attached to osmosis as accounting for the phenomena of absorption. Under certain circumstances substances are absorbed independently of this principle. For example, when tested experimentally outside the body, sugar is less diffusible than sodium sulphate, yet it is absorbed more rapidly from the intestine. Certain coloring-matters are not absorbed at all, the cells appearing to exert some selective action. It is also difficult to explain by osmosis the absorption of emulsified fats. It is probable that the protoplasm of the living cells on the walls of the intestine has some specific action.

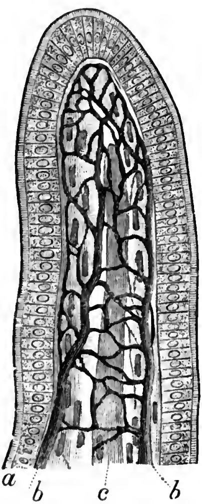
Sites of absorption: In the stomach and large intestine the absorption is very much less than in the small intestine, but there is reason to think that there is considerable activity to absorption from the entire gut so long as digestion continues.

Factors favoring absorption: (1) The valvulæ conniventes greatly increase the area of the intestinal surface, and by their

shelf-like formation delay the advance of chyme. (2) The villi of the intestine not only increase the area, but are the special organs of the function of absorption. (3) The contraction of the intestine upon its fluid contents also favors, mechanically, the filtration of the contents through its walls.

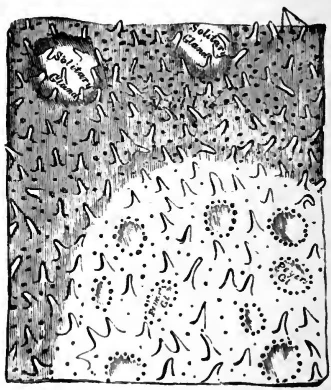
Villi of the intestine: The villi are almost innumerable, minute, teat-like projections from the surface of the wall of the intestine. They are very numerous in the small intestine, but none is found in the large gut. Each villus is covered by an epithelial layer, and within, supported by areolar tissue, is a delicate capillary network of bloodvessels, a muscular layer (muscularis mucosæ), and a more or less branched ending of a lacteal vessel (Figs. 58 and 59).

Fig. 58.



An intestinal villus. *a*, layer of cylindrical epithelium, with its external transparent striated portion; *bb*, bloodvessels entering and leaving the villus; *c*, lymphatic vessels, occupying its central axis (Leydig).

Fig. 59.



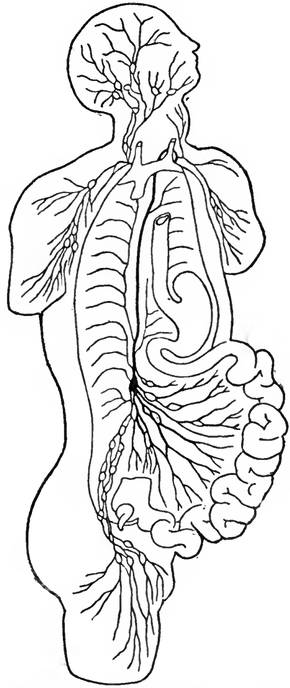
Patch of Peyer's glands, from the lower part of the ileum, showing villi (magnified).

The ileo-cæcal valve shows the absolute alteration which is apparent in the mucous membrane of the small as compared with the large intestine. On the side toward the ileum are found villi in great numbers, while its cæcal side shows none.

The lacteals are similar to the lymph-capillaries found in other parts of the body.

Changes in the products of digestion on being absorbed: The *proteids* that have been eaten are changed by the digestive fluids, as already explained, into peptones. These *peptones* are largely absorbed by the blood-capillaries of the digestive tract. In passing through the mucous membrane of the intestine the peptones are converted, in some unexplained manner, into *serum-albumin*. Hence we find that absorbed proteids exist in the blood as serum-albumin. Unconverted peptones would, if injected into the blood, act as a poison.

Fig. 60.



Lacteals and lymphatics during digestion.

The *carbohydrates* are converted by digestion into *maltose*. On being absorbed by the blood-vessels maltose is converted into *dextrose*.

The *fats* are highly emulsified and saponified. They are absorbed by the lacteals.

Water and *inorganic salts* are absorbed as such by the blood-vessels of the intestinal villi.

Peptones and sugars then are absorbed by the blood-capillaries of the stomach and of the small and large intestines, principally of the small intestine. Fats are absorbed only by the lacteals, hence only in the small intestine; water and inorganic salts, principally in the large and small intestines.

Destination of absorbed food: The food absorbed by the *lacteals* is collected from all the lymph-spaces in the villi and about the glandular structure of the intestines, and is taken

thence into the larger lacteals, whence it passes through the mesenteric lymphatic glands and into the receptaculum chyli of the thoracic duct (Fig. 60). Hence it passes on into the blood-vascular system, which it joins at the root of the neck at the union of the left internal jugular and subclavian veins.

The food absorbed by the *blood-capillaries* is brought to the liver by the portal veins.

On entering the liver the portal vein breaks up into capillaries, and thus the serum-albumin and dextrose are brought under the direct influence of the liver-cells.

The liver-cells allow only a small part of the *carbohydrates* (dextrose) to pass on and enter the general circulation. The remainder of the dextrose is acted upon by a ferment in the liver-cells, converting it into *glycogen*. The glycogen is then stored up in the liver until such time as the body needs more carbohydrates than the food eaten furnishes. When such demand is made upon it the liver reconverts some of the stored-up glycogen into dextrose and pours it into the general circulation.

The *serum-albumin* representing the proteid food-stuffs passes through the liver and into the general circulation.

Ultimate use of absorbed food: The absorbed food has now been followed into the general circulation. By the arteries the food-products are carried all over the body, to be used in building up the tissues. These same tissues ultimately, as the result of their lifework, are oxidized, broken up into carbon dioxide, water, and other wastes, to be finally eliminated from the body.

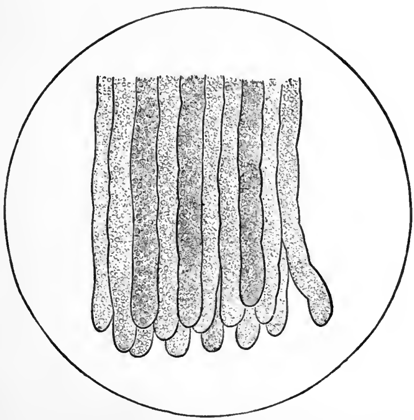
Conditions favoring food-absorption: To be absorbed by the bloodvessels or lacteals we must have substances *in a fluid state*, and the more dilute in solution the more ready the absorption; insoluble substances are not appreciably affected by this process, nor are any dense solutions readily taken up. The *rapid removal* of the absorbed matter and the *renewal* of fresh blood in the capillaries are of importance. Thus, if the portal circulation is obstructed, so that the blood is circulated slowly or the capillaries are tense from intravascular pressure, absorption will be slow.

SECRETION.

Secretions are materials separated from the blood by the cells to serve some further purpose in the animal economy. These secretions, for the most part, consist of substances which probably do not exist as such in the blood itself, but require special cells for their formation; for example, the liver-cells for the formation of bile, the stomach-cells for the formation of gastric juice, etc. The mucous and serous membranes also act in this capacity as well as the glands. Examples of secretions are found in milk, bile, gastric juice, tears, etc.

Excretions are materials which are *separated from the blood* by cell-activity and discharged from the body, being either

FIG. 61.



Follicles of Lieberkühn, from small intestine of dog.

useless or harmful if retained—*e. g.*, urine, sweat. They contain materials which exist in the blood in the same form, and are merely abstracted from it.

Processes of secretion and excretion: Secretion and excretion are carried on by means of the activity of the *cells* set aside for that purpose. In most cases the cells are grouped in organs which are known as glands. The serous fluids are the

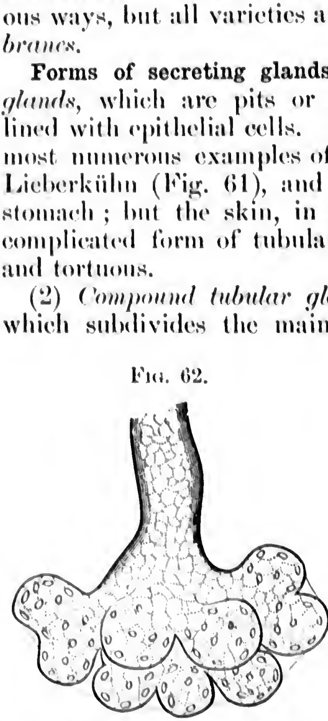
only notable exception to this rule, the endothelial cells secreting without the intervention of complex anatomical groups.

Structure of a secreting apparatus: The essentials of every secreting apparatus are the *primary* or *basement-membrane*, a simple and nearly textureless structure; certain *special cells*, and *bloodvessels*. These essentials may be combined in various ways, but all varieties are divided into *glands* and *membranes*.

Forms of secreting glands: (1) *Simple tubules*, or *tubular glands*, which are pits or depressions in epithelial surfaces lined with epithelial cells. The mucous surfaces furnish the most numerous examples of this form of gland, follicles of Lieberkühn (Fig. 61), and tubular (mucous) glands of the stomach; but the skin, in the sweat-glands, shows a more complicated form of tubular gland in that it is convoluted and tortuous.

(2) *Compound tubular glands* consist of a tubular gland which subdivides the main tubule, so as to have several branching tubules leading into it. Often these branches again subdivide so as to form a group of ultimate glandular elements grouped about the main tubule, which acts as a duct. This form of gland is found in kidney, testis, salivary and mammary glands, Brunner's glands (Fig. 62), and in many of the other glandular structures.

FIG. 62.



Portion of one of Brunner's glands, from human intestine.

(3) *Racemose*, or *aggregate* glands, in which the glandular structure is divided into lobules, or *acini*. These glands may be regarded as a refinement of the compound tubular variety, and examples are found in the salivary glands and in the Meibomian follicles

Processes of secretion: (1) By *physical* processes—viz., filtration and dialysis—the cells are able to separate from the

blood-plasma the ingredients which make up the secretion. It is important to remember that the force of dialysis may actually operate against pressure, and is, consequently, not a mere negative process; and, again, the fact that the condition of the blood as to consistency and saline ingredients makes filtration a sort of check-valve upon the permanency of the blood-condition.

(2) By *chemical* processes the cells of glands manufacture new substances not found in the blood-plasma and add them to the secretions. These processes are peculiarly noticeable in the ferment-producing glands—salivary, peptic, and pancreatic.

Discharge of secretions: The secretions may be discharged from the glands as soon as they are formed, as in the case of the sweat-glands. They may be long retained in an undeveloped form in the *cells* of those glands whose activity is only occasional; or in a fully developed form in their *ducts*. Certain glands, such as the lachrymal, which belong to both classes, constantly secrete small amounts, but increase this amount when stimulated.

Conditions affecting glandular activity: (*a*) If the *amount of blood passing through a gland* be increased, there will be increased activity of the function; and, conversely, as a rule, during functional activity the gland will increase in vascularity. The stomach, for example, during digestion is quite engorged, but when idle is supplied with much less blood; as is seen by the color deepening during its period of activity.

(*b*) An *increase in the material upon which the gland acts* stimulates the gland to greater effort and increases the production of the gland. Thus, the amount of urea is increased by an increase of nitrogenous waste, as by exercise, or by an increase of nitrogenous matter in the blood, as by a full meal of animal food.

(*c*) The *nervous system exerts an active influence* upon secretion. This is usually reflex in character, and frequently is active through the vaso-motor nerves, as when the salivary and gastric secretions are increased by the sight or smell of food, as well as by its actual administration. There is also a

so-called *trophic* influence of the nervous system, which directly affects the secreting power of a gland: this is especially well shown in the case of the chorda tympani in its relation to the secretion of the submaxillary gland.

Correlation of secretions: There often seems to be a relation in the amount of one secretion to that of some of the others; thus in a diseased condition of the intestinal mucous membrane, with increased secretion, there will often be an increase of the bile secreted, and perhaps a diminution of other secretions, as salivary or urinary. And, again, unusual perspiration is followed by decrease in the activity of the kidneys.

Having studied the general subject of secretion, the matter will be best pursued if we study the individual secreting and excreting glands.

Serous Secretions.

The **serous secretions** are the products of the activity of the cells of the pleura, peritoneum, pia mater, and tunica vaginalis; also of the synovial membrane of joints, tendon-sheaths, etc. The secretion of the synovial membranes is far more glairy and viscid than is that of the true serous membrane.

The *purpose* of serous secretion is to lubricate surfaces in which friction is undesirable. The serous membranes are characterized by having a single layer of polygonal endothelial cells covering their free surface. The fluid secreted appears to be identical with very dilute liquor sanguinis It is pale yellow or straw color, alkaline, slightly viscid, and, because it contains albumin, is coagulable by heat.

Mucous Secretions.

Mucus is secreted by the mucus-cells of glands opening onto mucous membrane. It is a more or less viscid, semitransparent, alkaline fluid of high specific gravity, containing epithelium and leukocytes. It consists of a large amount of *mucin*, a little albumin, water, salts, and traces of fats and

extractives. The *object* of the secreted mucus is to keep moist and soft the delicate cells of the mucous membrane; also at the same time the mucus acts as a lubricant. Mucous tracts which are so protected are the digestive, respiratory, and genito-urinary.

Mammary Glands.

The **mammary glands** are large structures which are made up of several distinct lobes. Each lobe has its duct, which leads to the nipple, and there are about twenty such lobes and ducts. The lobes are subdivided, and the small lobes, or lobules, are made up of the terminal tubules of the duct, which lie in a mesh of fibrous areolar tissue containing considerable fat in its reticulum. The ultimate divisions (alveoli) of the terminal tubules are lined with columnar epithelial cells, as are the ducts and their branches, but the epithelium of the ducts becomes flat (squamous) near the nipple. The main ducts (lactiferous ducts) are sacculated, and during lactation the secretion of the alveoli collects in them, and is drawn from them through their small orifices in the nipple. The flow of milk is also aided by the presence of a small amount of unstriped muscular fibre in the wall of the ducts.

The mammæ are abundantly supplied with bloodvessels, lymphatics, and nerves, and during pregnancy and lactation the vessels, as well as the gland, undergo considerable increase in size.

Milk: The secretion of the mammary gland is a bluish-white fluid. It is opaque, and this opacity is caused by the presence of minute fat-globules which are held suspended—an emulsion. Besides the fat-globules the microscope shows in milk from a newly active gland certain albuminous bodies which are known as colostrum-corpuscles. They are probably cells from the gland which are undergoing fatty degeneration. Milk is alkaline in reaction, and has a specific gravity of about 1030.

Composition of milk: The ingredients of milk are water, containing in suspension fats and in solution casein, serum-albumin, milk-sugar, and salts. Human milk differs from

cows' milk in containing less proteids and fats and more sugar:

	Human milk.	Cows' milk.
Water	890	858
Proteids	35	68
Fats	25	38
Sugar	48	30
Salts	2	6
	1000	1000

Cream: The fat-globules rise to the top if milk is allowed to stand, and are called cream. By agitating or "churning" the cream the albuminous envelopes of the fat-globules are broken, and they coalesce to form a fat mass known as *butter*.

Secretion of milk: The activity of the mammary glands does not begin until the individual has become pregnant—in fact, the secreting alveoli are not fully formed until the first pregnancy. During the period of gestation there is no true milk secreted, but the cells are developing and preparing for their functions. There is formed during the latter part of pregnancy a secretion somewhat similar to milk, called **colostrum**. It differs from ordinary milk in containing a larger quantity of solid matter. Under the microscope are to be seen certain granular masses, called *colostrum-corpuscles*, which have been seen to exhibit contractile movements. Its chief value lies in the fact that it acts as a laxative, thus insuring an emptying of the infant's intestinal canal. The formation of colostrum is marked during the first two or three days after labor, followed by secretion of true milk.

The *continued secretion* of milk is only kept up by the stimulus of the nursing infant. If the child be weaned, the milk-producing cells rapidly cease to secrete. The nerve-supply regulating secretion of milk has not been definitely proven.

Milk as a food: As the food of all young animals it must be considered of the greatest importance; besides this, as a direct food, both in the natural state and in the derived forms

of butter and cheese, it is one of the most used articles of adult diet. The causes which lead to its choice in the dietary are easily seen: it contains all the elements necessary to sustain life—water, proteids, carbohydrates, and fats. As an exclusive diet it will probably sustain life better than any other substance.

Digestion of milk: When milk taken as food enters the stomach it is first acted upon by *rennin.*

Rennin is a milk-curdling ferment, its property being to convert the soluble proteid *casein* into an insoluble curd. The digestion of the curd is by the hydrochloric acid and pepsin. The digestion of the remaining elements of milk is the same as that of other proteids, carbohydrates, and fats.

Besides rennin of the stomach, there are other milk-curdling ferments that will act upon milk so as to cause its separation into curds and whey. They are found in the pancreas and intestine.

"Souring" of milk: There is also a curdling of milk produced when an acid is added to milk. This is called "souring." In nature the acid is made by the breaking up of milk-sugar (lactose) to form lactic and butyric acids, through the action of a micro-organism, the "bacterium lactis."

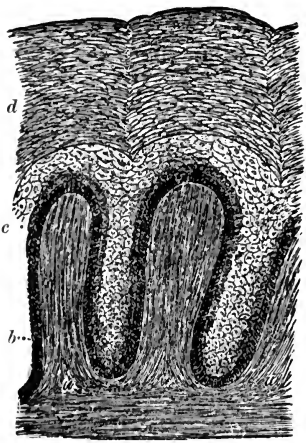
Secretions of the Skin.

The skin: The skin acts as a general protective and sensory covering for the outer surface of the body. It also acts to a certain extent as an absorbing surface. As we shall see later, it acts as an excretory organ and as an important heat-regulator. There are two layers of tissue which form the entire thickness of the skin. The superficial epithelial layer is known as the *epidermis* or *cuticle;* the deeper stratum, in which lie the active functional elements, is called the *cutis vera*, *corium*, or *derma.*

Epidermis: The epidermis is a stratification of epithelial cells, of varying thickness. The epithelium is flat and horny at the surface; in the deeper portions are flattened and polyhedral cells; and it is closely adapted to the surface of the corium beneath it (Fig. 63). In its deeper layer is found the

pigment which characterizes the complexion of individuals and of races. Its function is purely one of protection. The growth to replace worn-out cells is very rapid, and in cases of considerable use of a part, with interrupted pressure upon the skin, the cuticle becomes very thick and horny, as is often seen upon the hands and feet. The hair and nails are modifications of the epidermal epithelium.

Fig. 63.



Skin of the negro, vertical section, magnified 250 diameters. *a*, *a*, cutaneous papillæ; *b*, undermost and dark-colored layer of oblong vertical epidermis-cells; *c*, mucous or Malpighian layer; *d*, horny layer (Kölliker).

Corium: The true skin is a tough, elastic tissue composed of interlacing bundles of connective-tissue cells containing spaces between the fasciculi. These spaces are known as *areolæ*. There are also numerous unstriped muscular fibres. This structure lies upon a more or less thick layer of fatty or loose cellular tissue. In the cutis are found the active organs of the skin—papillæ, sweat- and sebaceous glands, and the hairs (Fig. 64).

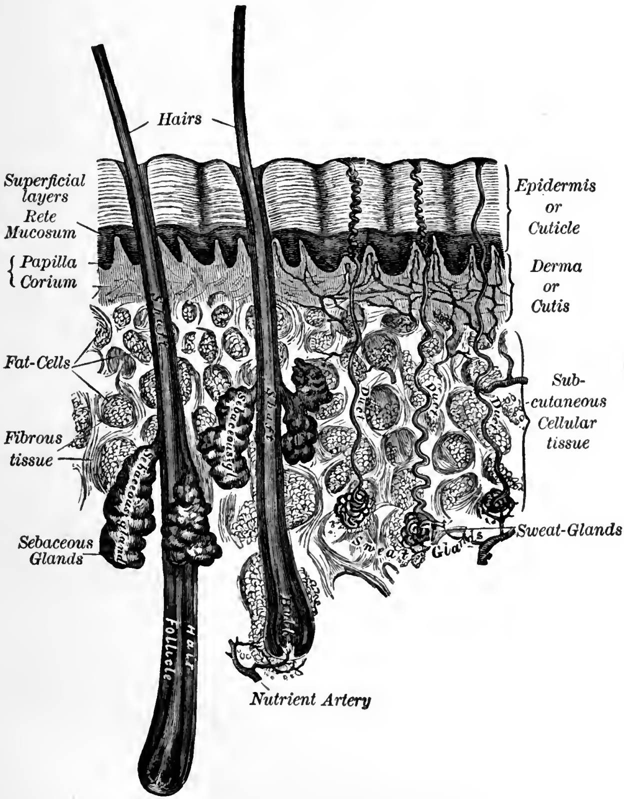
Papillæ: Upon the superficial surface of the cutis vera are innumerable minute elevations which project into the epithelium. They are very vascular, and contain the nerve-endings which give to the skin its sensibility, the sense of touch. The papillæ are especially abundant upon the parts in which this sense is most acute—palms, finger-tips, soles.

Sweat-glands: Each gland lies in the subcutaneous fat, and consists of a convoluted mass of tubules which terminates in a duct leading up through the derma and epidermis, discharging the secretion of the gland through a minute opening. This secretion is known as *perspiration*, or *sweat*.

Sebaceous glands: The sebaceous glands occur everywhere over the entire skin surface with the exception of the palms and soles, and most abundantly in the hairy parts. They are

intimately connected with the hair-follicles; and their ducts, as a rule, open into the follicles, though sometimes they discharge separately. The glands are aggregate glands—that is,

FIG. 64.



Sectional view of the skin, magnified.

are formed by the subdivision of the duct to make up the lobules of the gland. There is a delicate plexus of capillary vessels about the sacculi.

Hair: A hair is produced by a peculiar growth and modi-

fication of the epidermis, especially of the rete mucosum. It consists of a bulb or root imbedded in the skin and of a projecting shaft. It is composed of a central medullary substance, around which is disposed a thick layer of elongated horny cells—the *cortex*. On the outside is a layer of fine scales, closely overlapping with the edges turned upward, known as the *cuticle*. The root of each hair is lodged in the *follicle*, a tubular depression of the skin descending into the subcutaneous fat. At the bottom of the follicle is a small papilla of true skin, by the projection and outgrowth of whose cells the hair is formed (Fig. 65).

FIG. 65.

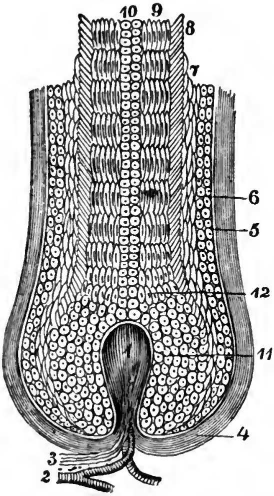


Diagram of structure of the root of a hair within its follicle. 1, hair-papilla; 2, capillary vessel; 3, nerve-fibres; 4, fibrous wall of the hair-follicle; 5, basement-membrane; 6, soft epidermis lining the follicle; 7, its elastic cuticular layer; 8, cuticle of the hair; 9, cortical substance; 10, medullary substance; 11, bulb of the hair composed of soft polyhedral cells; 12, transition of the latter into the cortical substance, medullary substance, and cuticle of the hair (Leidy).

Nails: A nail, like a hair, is produced by modified skin. It consists of two layers, a superficial horny one, composed of flattened nucleated cells or scales, and a deeper soft layer, corresponding to the rete mucosum of the epidermis. The back edge of the nail—the *root*—is received in the groove of the *matrix*, a specially modified part of the corium. The growth of the nail, like that of the hair, is due to a constant production of cells from beneath and behind in the matrix.

The **sweat** is a watery fluid, colorless, slightly turbid, slightly salty to the taste, of acid reaction, and possessing a peculiar odor. It is an excrement. Its composition is somewhat variable, but in general it may be said to contain about $\frac{1}{2}$ per cent. of solids suspended and dissolved in water. These solids are fats and fatty acids, sodium chloride, epithelium,

and a trace of urea. Besides these there is a considerable amount of carbonic dioxide (CO_2) excreted by the skin.

Nervous mechanism of perspiration: It is probable that the sweat-glands are under the reflex control of centres in the medulla and in the spinal cord, and that these centres regulate this function of the skin through the vaso-motor system.

Amount of sweat: The amount of sweat excreted depends on the condition of the atmosphere, the nature and quantity of the food, the amount of fluids consumed, the exercise taken, and the relative activity of the other glands, especially of the kidneys. Certain mental conditions, some diseases, and drugs also interfere with sweat-secretion. In general, we may say the amount is about a quart in twenty-four hours.

Odor of sweat: The odor of sweat varies for different parts of the body, and markedly for different races of mankind. The odor is due to various acids found in the sweat—formic, acetic, butyric, propionic, caproic, and caprylic.

Purpose of sweat: The sweat is an excrement, and so we consider the skin as an excretory organ. The principal substances excreted in the sweat are water, carbon dioxide, and urea.

In addition to being a means of excretion, the sweat is of great value as a regulator of body-heat. By evaporating from the surface the sweat cools the body.

Insensible perspiration: When the secretion of the sweat-glands forms in drops upon the skin we speak of this as *sensible* perspiration, or *sweat*. However, since the glands are continuously active, there are times when the fluid evaporates so rapidly that no moisture is noticeable upon the surface; this is called *insensible* perspiration.

Secretion of sebaceous glands: The secretion of the sebaceous glands is a soft, oily, white material, and has, besides other fats, stearin for basis. Its use seems to be to lubricate the skin, keeping it soft and flexible, and at the same time, by its oily nature, to prevent maceration of the skin from continued exposure to moisture; and to check undue absorption from the surface. Sebaceous matter is not excrementitious, but is a secretion.

Absorption by the skin: In addition to its excretory and secretory properties, the skin has the power of absorption. This function admits of the application to and absorption by the skin of certain medicines, food, and drink.

In frogs, for example, the skin has the power, if kept moist, of absorbing oxygen; it is by virtue of this property that a frog can oxygenate its blood under water.

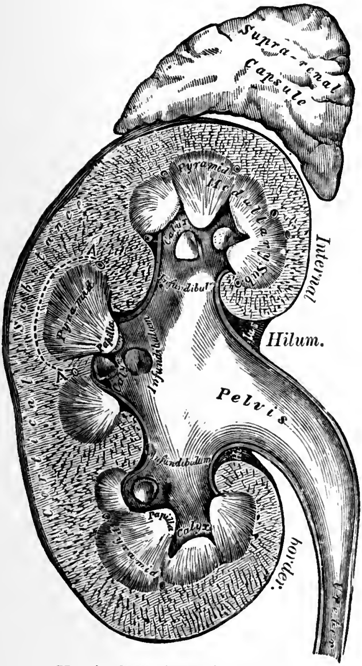
Necessity of sweat: Sweating is an absolute necessity to life, in order to assist the other excretory organs in removing the wastes of the body. The symptoms of complete suppression of the insensible sweat are those of an acute poisoning, together with pyrexia and exhaustion. This can be proven by varnishing the skin of animals, which causes death. A celebrated instance of this is the case of a child who, being covered with gold-leaf to personate an angel at the coronation of Leo X., died a few hours afterward.

Kidneys and Urine.

The **kidneys** are glandular organs having somewhat the form of a bean. In size they are somewhat more than 4 inches in length, somewhat more than 2 inches wide, and about 1 inch thick. The weight of each organ is about 4 to 6 ounces. A thin but rather tough capsule invests the kidney (Fig. 66). This may be pulled off readily, leaving the surface of the organ smooth and even and of a deep-red color. If a vertical section of the organ be made, the central cavity (sinus) will be noticed, and about it the kidney-tissue. Within the sinus are the apices of pyramidal projections, about ten in number; and if the cut surface be examined closely, it may be noted that the outer (cortical) portion differs in appearance from the more central (medullary) portion. The blood-supply is from the renal artery, and the nerve-supply is from the sympathetic system through the solar plexus. The kidney is a compound tubular gland. The *medullary* portion of the organ is almost entirely made up of tubules, which take origin in the cortex and empty upon the apices of the pyramids of Malpighi of the medullary portion (see below).

Malpighian bodies: In the cortical portion of the kidneys are found minute tufts of capillaries which are surrounded by a capsule lined with epithelial cells (Fig. 67); and here it is that the uriniferous tubules arise, the tuft of capillary vessels being, as it were, built into the end of the tubule.

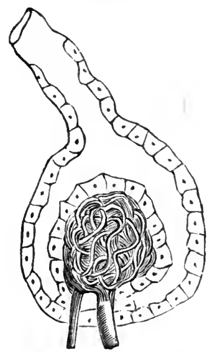
Fig. 66.



Vertical section of a kidney.

Uriniferous tubules: Beginning in the cortex of the kidney at one of the bodies of Malpighi, the minute se-

Fig. 67.



Malpighian body.

creting ducts pursue a tortuous course to the larger collecting tubules, which empty at the apices of the pyramids of Malpighi into the *calyces* of the kidney (see Ureters). Without entering minutely upon the course of the tubules, it is important to remember that they form a loop (of Henle) which dips into the pyramid, and that they pursue a somewhat tortuous course both before entering into the loop of Henle and upon returning to the cortical portion of the kidney, where they empty into the straight collecting tubules. The straight course of the arms of Henle's loop and of the collecting

tubules gives to the pyramids a finely striated appearance (Fig. 68). These collecting tubules en masse, together with interstitial tissue, bloodvessels, and lymphatics, make a "pyramid."

FIG. 68.

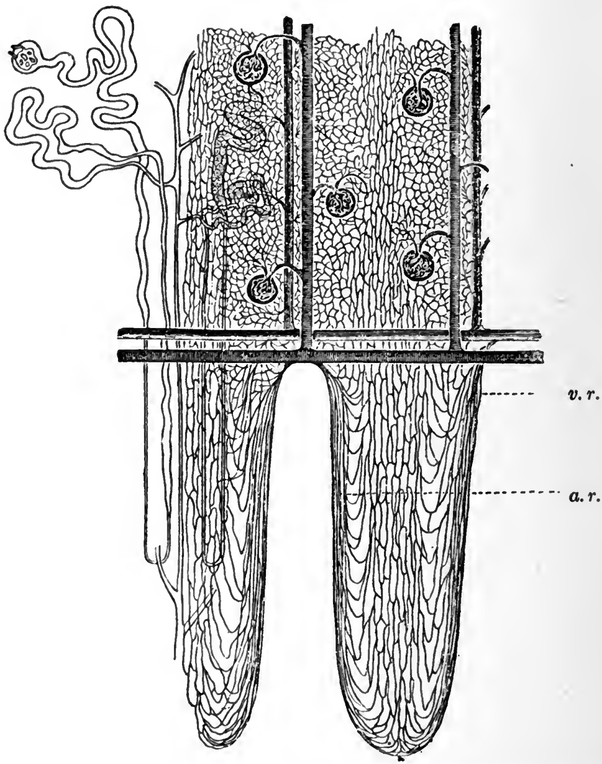


Diagram of the tubules and vascular supply of the kidney. On the left is a tubule alone; in the middle is a tubule along with the bloodvessels; on the right are bloodvessels only. *v. r.*, venæ rectæ; *a. r.*, arteriæ rectæ.

Blood-supply of kidney: On entering the kidney the renal artery breaks up into several branches, which pass into the tissue proper of the organ. Branches from these arteries

(arteria propria renales) have two determinations—(1) into the cortex and (2) into the pyramids.

(1) Those branches (interlobular) which pass into the cortex divide to become the *afferent* vessels to the Malpighian bodies, and, after there passing through the capillary tuft, the blood is re-collected and goes out by an *efferent* vessel. This efferent vessel in its turn is broken into a minute capillary plexus which surrounds the uriniferous tubules in the cortex of the kidney, and these capillaries unite to form the venous return-circulation (interlobular veins). Thus, this system has, it is to be noted, two capillary divisions, in the Malpighian tuft, and again about the tubules of the cortex. There is also a *sub-capsular* capillary division, derived from certain of the interlobular vessels that do not go to nor come from the Malpighian bodies.

(2) Numerous minute branches (arteriæ rectæ) are given off, which pass into the pyramids as far as their apices, and there form capillary divisions from which the venæ rectæ return to join the branches from the cortex and form the venæ propriæ of the kidney.

The ureters: Leading from each kidney to the bladder is a duct—the ureter—about the size of a goose-quill and from twelve to sixteen inches in length. The ureters are lined with mucous membrane, continuous above with that of the pelvis of the kidney, and below with that of the bladder. The "pelvis of the kidney" is the upper dilated end of the *ureter*; and, in its turn, is made up of the conjoined calyces (see Uriniferous Tubules).

The bladder: This, which forms a temporary receptacle for the urine, is a hollow muscular organ of a pyriform shape, lined with mucous membrane, and situated in the pelvic portion of the abdominal cavity. The widest part is called the *fundus*, and the narrowed part, whence leads the urethra, is sometimes known as the *cervix*.

Urine: It is a clear, amber-colored fluid of slightly acid reaction. It may develop a flocculent precipitate of a light cloud of mucus upon standing. It has a characteristic odor and a salty-bitter taste.

Urine has a *specific gravity* of about 1020; but under con-

ditions of health it may vary from 1010 to 1030, or even beyond these limits.

Coloring-matter of urine: The coloring-matter of the urine appears to be identical with hydrobilirubin. It is derived from the bilirubin of the bile, which, being absorbed, passes out of the body in the urine rather than in the fæces. The varying tints are probably due to oxidation of this substance.

Composition of urine: The urine is an excrementitious fluid, and may be considered as a watery solution of the excrementitious products of the retrograde metamorphosis of nitrogenous bodies, resulting from the processes of life and action. Chemically, it is a solution of urea and urates with a small percentage of organic salts.

Table of the Chemical Composition of the Urine.

Water	967
Crystallizable nitrogenous bodies:	
Urea	14
Uric acid, free (trace), Uric acid in form of alkaline urates, Hippuric acid and hippurates, Pigments, extractives, and mucus, (All in small and constant amounts).	11
Salts:	
Inorganic—	
Chlorides of sodium and potassium, Sulphates and phosphates of sodium and potassium, Phosphates of magnesium and calcium, Silicates (trace), *Organic*— Lactates, acetates, and formates, which only appear occasionally.	8
Sugar (occasionally), a trace,	
Gases, nitrogen, and carbonic acid.	
	1000

Acidity of urine: The acidity of the urine is due to the

presence of acid sodium phosphate. There is no free acid present, as is shown by the fact that no precipitate is formed upon the addition of sodium hyposulphite. The degree of acidity varies, being less during active digestion and less after vegetable food. Herbivora have alkaline urine, while carnivora have strongly acid urine ; but the herbivorous animal during fasting has acid urine, because it is then living from its own tissues and is for the time a carnivore. After excretion, however, the urine soon becomes more acid (probably because of the presence of some fermentation), and at this time uric acid and urates may precipitate. Upon further exposure it is attacked by micro-organisms, and the urea is changed to ammonium carbonate, the reaction becoming alkaline, and there is a precipitation of triple phosphates and alkaline urates. In the body these conditions do not occur in conditions of health.

Secretion of urine: The kidneys secrete urine in two ways: (1) by filtration and (2) by real functional action of the epithelium.

(1) In the circulation of the blood through the Malpighian tuft there seems to be no active separation of the urinary ingredients by cell-power, but the water and saline elements are given off here by the blood by a process of simple filtration. The amount of fluid which passes here is governed by the blood-pressure in the arteries of the kidney and by the fluidity of the blood.

(2) The epithelium of the uriniferous tubules has secreting function, and is able to *separate* from the blood foreign substances (*e. g.*, urea or indigo-carmine) and eject them into the tubules, and to *manufacture* from material taken from the blood new substances not found there (*e. g.*, pigments).

Amount of urine: The average amount of urine secreted daily is fifty-two fluidounces, though as little as thirty-five ounces, or as much as eighty-one, may be voided within the limits of health. The quantity varies greatly in health with the amount of fluid taken, of food consumed, of the activity of the skin evaporation, and somewhat with the character of the food. In a more general way it may be said to depend upon the condition of the blood, an excess of fluids demand-

ing increase of functional activity on the part of the kidneys. In conditions of disease or under the stimulus of drugs the limits mentioned are by no means final, for in certain pathological conditions the secretion may be almost wholly suspended or very greatly increased.

Conditions affecting urinary secretion: The factors that favor the increase of urine are those conditions which favor filtration of water by the glomeruli of Malpighi—that is, the presentation of a larger amount of blood to the action of these bodies. This is accomplished—

(1) By increasing the force of the heart.

(2) Through the nervous system by its action upon the vascular, so as to produce local congestion. The effect of the nervous system in increasing the urine by reflex vaso-motor impulses is felt most in the glomeruli, and the urine is therefore very watery.

(3) By conditions which cause anæmia of other parts, thus producing a greater determination of blood to the kidneys, and so increasing the urinary flow. So marked is this that the skin and kidneys may almost be said to be complementary in their action in eliminating water from the system; and in this regard their relative activity may be said to be inversely proportional to one another.

Kirke gives the following table (modified from Foster), which is useful for reference:

Table of the Relation of the Secretion of Urine to Arterial Pressure (Kirke).

A. Secretion of urine may be increased—

a. By increasing the general blood-pressure—by

1. Increase of the force or frequency of the heart-beat.
2. Constriction of the small arteries of areas other than that of the kidney.

b. By increasing the local blood-pressure by relaxation of the renal artery, without compensating relaxation elsewhere—by

1. Division of the renal nerves (causing polyuria).
2. Division of the renal nerves and stimulation of the cord below the medulla (causing greater polyuria).

3. Division of the splanchnic nerves; but the polyuria produced is less than in 1 or 2, as these nerves are distributed to a wider area, and the dilatation of the renal artery is accompanied by dilatation of other vessels, and therefore with a somewhat diminished general blood-supply.
4. Puncture of the floor of the fourth ventricle or mechanical irritation of the superior cervical ganglion of the sympathetic, possibly from the production of dilatation of the renal arteries.

B. Secretion of urine may be diminished—

a. By diminishing the general blood-pressure—by

1. Diminution of the force or frequency of the heart-beats.
2. Dilatation of capillary areas other than that of the kidney.
3. Division of the spinal cord below the medulla, which causes dilatation of the general abdominal area, and urine generally ceases being secreted.

b. By increasing the blood-pressure—by stimulation of the spinal cord below the medulla, the constriction of the renal artery which follows not being compensated for by the increase of the general blood-pressure.

c. By constriction of the renal artery—by stimulating the renal or splanchnic nerves or the spinal cord.

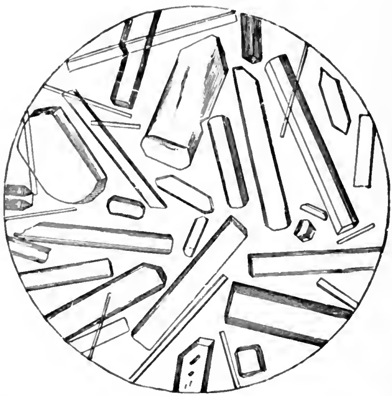
Course of the urine: The urine collected in the tubules of the kidney passes into the pelvis of the kidney, and is carried to the urinary bladder in irregular quantities by the ureter. The ureters simply act as ducts, and do not store up urine, nor do they usually actively eject it into the bladder. As a few drops of urine collect in the pelvis of the kidney, they run into the bladder, the action of the two kidneys not being in alternation nor absolutely regular in point of time. Regurgitation from the bladder is prevented by the oblique course of the ureter through the muscular wall of the bladder.

Micturition: When the bladder is filled the act of emptying

it is called micturition. It is a voluntary act, aided by the involuntary reflex contraction of the muscular coat of the organ itself. The voluntary muscles involved are those of respiration—the diaphragm and the abdominal muscles. So far as micturition is *involuntary*, it is a reflex depending upon a centre in the lumbar spinal cord.

Urea is a chemical body, the formula being CH_4N_2O (Fig. 69). The nitrogen atom is derived from the "combustion"

FIG. 69.



Urea, prepared from urine, and crystallized by slow evaporation (Lehmann).

of proteid material. Hence we infer that the amount of urea excreted gives us an index of the amount of proteid material consumed by the body. The used-up nitrogenous matters of the body may be derived from: (1) the food (urea being greatly increased by a nitrogenous meal); (2) the metabolism of the tissues.

The result of the "combustion" of nitrogenous material is not at once found in the blood, but exists as some antecedent of urea (probably carbonate of ammonium) until the blood reaches the liver. Under the action of the liver-cells the antecedent of urea is converted into urea. The urea thus formed remains in the circulation until the blood reaches the kidney; here the urea is excreted. Thus it is seen that the kidney-

cells play no part in the formation of urea, but merely exert a selective action upon it for excretory purposes.

Amount of urea excreted: The amount varies, but it may be considered to be about one-half the solid constituents of the urine. Roughly speaking, the urinary solids may be regarded as 4 per cent. of the total, and the urea (including the uric acid and urates) about 1.5 to 5 per cent. This proportion is very variable, and there may be urea in healthy urine to exceed $2\frac{1}{2}$ per cent., or in a much less ratio than 5 per cent.

Method of estimating solids: A useful rule for approximately estimating the total solids in any given specimen of healthy urine is to multiply the last two figures representing the specific gravity by 2.33. Thus, in urine of specific gravity 1025, $25 \times 2.33 = 58.25$ gr. of solids in 1000 gr. of urine. In using this method it must be remembered that the limits of error are much wider in diseased than in healthy urine.

Urea as a waste: Urea is capable of still further oxidation, and so would be a source of further chemical potential energy; but urea is excreted before it is fully oxidized, and so is a real waste.

Uric acid: Of the other constituents of urine, uric acid is the most important, it being one of the forms in which nitrogen is eliminated. It usually exists in the urine in the form of urate of ammonium or sodium. It probably comes, like urea, from food-disintegration. Some consider it to be an imperfectly oxidized form of urea. The amount found in the blood is especially increased in gout.

Hippuric acid: This is one of the few important constituents of urine which is produced in the kidneys themselves, being formed from benzoic and amido-acetic acids. It is also formed in the liver. It is another form of nitrogenous elimination, but may come from tissue-waste as well as food-disintegration. It exists in slightly larger quantity than does uric acid.

Vascular Glands.

The **vascular glands,** or ductless glands, are a collection of glandular structures that possess no ducts and apparently do

not seem to be associated in either secretion or excretion. Ductless glands include the spleen, thyroid, thymus, and tonsils.

Purpose of ductless glands: No definite function has been ascribed to the ductless glands; but we do know that the extirpation of certain of these structures is attended with serious results to the subjects. For example, congenital defects of the thyroid produce the condition known as cretinism.

Table of Secretions.

Secretion:	Secreting organ:	Reaction:	Main Purpose:
Sebum;	Sebaceous glands of the skin;	Acid;	To oil the skin.
Mucus;	Mucous cells of mucous membranes;	Alkaline;	Lubricant and diluent.
Serous secretion;	Serous membranes;	Alkaline;	Lubricant and diluent.
Tears;	Lachrymal glands;	Alkaline;	To moisten conjunctivæ.
Saliva;	Salivary glands;	Alkaline;	To moisten food and digest carbohydrates.
Gastric juice;	Stomach;	Acid;	To digest proteids.
Succus entericus;	Intestines;	Alkaline;	To dilute the chyme.
Pancreatic juice:	Pancreas;	Alkaline;	To digest proteids, fats, and carbohydrates.
Bile;	Liver;	Alkaline;	Part of the bile is used in digestion and reabsorbed. Part is a true excretion (bile-pigments).
Milk;	Mammary glands;	Alkaline;	Food.
Sweat;	Sweat-glands of skin;	Acid;	Elimination of water, carbon dioxide, and urea. Regulates body-temperature.
Urine;	Kidneys;	Acid;	Elimination of water and urea.

NUTRITION.

By **nutrition** we mean the physiological principles which preserve the normal conditions of the structure and function of the body, so far as refers to the balance between the income and outgo of material. While it is almost an impossibility to study this subject exactly, yet an idea of the modes of expense and income may be gained by consideration of data which are fairly well settled. In considering the income and expenditure of the body it is always necessary to bear in mind that all the factors are variable and the results inconstant, for the income often exceeds the expense, and *vice versâ*, in life.

Sources of income to the body: Food and drink and oxygen are the factors of the income, and may be calculated about as follows for twenty-four hours:

Food (chemically dry)	16	ounces.
Water (as drink and as combined with solid food)	80	"
Oxygen (absorbed by lungs)	26	"
Total,	122	ounces.

Expenditures of the body: The more important are those by the ordinary excretory channels—lungs, skin, kidneys, and intestines.

From the lungs there are exhaled every twenty-four hours—				
Of carbonic acid, about . . .	30	ounces.		
Of water	10	"	40	ounces.
Traces of organic matter.				
From the skin—				
Water	23	"		
Solid and gaseous matter . . .	1	ounce.	24	"
From the kidneys—				
Water	50	ounces.		
Organic matter	$1\frac{1}{2}$	"		
Minerals and salines	$\frac{1}{2}$	ounce.	52	"
From the intestines—				
Water	4	ounces.		
Various organic and mineral substances	2	"	6	"
Total,			122	ounces.

Thus we may represent the schematic plan of income and expense as about equal; but it must be borne in mind that the plan only represents an average result of both.

Variations in the rate of income and expenditures are shown by changes in the body-weight.

Results of body-expenditure: In return for the amount of food, drink, and oxygen the body has consumed, we have to show for it:

(1) The *growth* of the body and secretion of its necessary materials, as well as the *maintenance* of the tissues, subjected as they are to the wear incident to the continuance of life and function.

(2) The continuance of physical conditions suitable to life in the form of *heat* and *motion*. The actual combustion of carbon (*i. e.*, oxidation) must be sufficient to maintain the animal heat and the nourishment of the muscles upon which the continuance of life depend.

(3) *Nervous energy*, as in the regulation of all physiological processes by the reflexes, as well as in voluntary mental and nervous action.

Energy of the body: The daily work of the body has been calculated to be about 3400 foot-tons. Of this about one-tenth has been considered to be exhausted in involuntary muscular action (circulation, respiration, etc.) and in voluntary motion, while the remainder (nine-tenths) is expended in maintaining the body-heat. Another method of considering this enormous force may be of use: it is equivalent in heat to that required to raise nearly fifty pounds of water from the freezing- to the boiling-point; or in mechanical force it is sufficient to raise the body of a man weighing one hundred and fifty pounds to a height of eight and one-half miles.

Effect of starvation: There is a loss of weight in all the tissues, but it is in the loss of the fat that the change is most marked: the fat almost entirely (93 per cent.) disappears after death from starvation. The sense of hunger gives way to a sense of pain; thirst is excessive; sleep is absent; progressive weakness accompanies increasing emaciation; the exhalations of the skin and lungs are fœtid; and diarrhœa with convulsions or delirium often precedes death. Death occurs with absolute deprivation of both food and drink at the end of about a week (six to ten days), though life may be considerably prolonged by small quantities of food or water. The temperature of the body falls before death very considerably (30° C.), and it has been considered that death results from cold, no fuel being furnished to maintain animal heat. The body decays rapidly after death from starvation.

"Exclusive" diet: The result of feeding animals exclu-

sively on a single article of diet (sugar, gum, oil, etc.) is practically the same as that of starvation, except that death does not occur until the end of four or five weeks. In man the exclusive diet of isolated communities often results in the breaking down of tissue and general malnutrition.

Effect of over-feeding: An excess of nitrogenous food, if digested, increases the metabolic work of the glanular organs (especially of liver and kidneys), and induces disease in those organs and faulty excretion of nitrogenous matter. This may be obviated or delayed by active physical exercise. Carbohydrate food in excess is stored up in the form of fat, which may be excessive, with resulting fatty infiltration of the viscera, or it may show as glycosuria.

An excess of any food is apt to pass undigested through the intestines and undergo putrefactive changes, with resulting gaseous distention: the carbohydrates are especially apt to give rise to this disturbance.

Normal diet: There should be a general diet of well-cooked food, and it should contain about the amount of carbon and nitrogen which is excreted; that is, it should maintain an equilibrium. This is, commonly, about two pounds of solid food and two quarts of fluid. The proportion of the various kinds of food varies considerably, but in a general way for a healthy man, one may divide the solid food somewhat in this way: nitrogenous food (meat), about $\frac{1}{2}$ pound; hydrocarbon and fat-food (bread, vegetables, and butter), about $1\frac{1}{2}$ pounds. Besides this, the food will contain from 1 to 2 ounces of salts and a varying amount of sugar.

"**Nitrogenous equilibrium**": When an animal is fed exclusively upon a nitrogenous diet, it is found that after a time the egested nitrogen approaches and finally balances that taken in as food. This is known as the "nitrogenous equilibrium." But at the same time the animal may increase in weight, and this occurs by the formation of fat which is stored up in the tissues. The nitrogenous equilibrium is more easily maintained by the addition of carbohydrates to the food.

It is also known that the fat of the body not only comes from the fat we eat, but is also made from carbohydrates and

proteids. So, too, carbohydrates may be manufactured from proteids. Hence the animal fed on nitrogenous diet exclusively may store up some fat that has been manufactured in its body from the proteids.

Assimilation: It seems almost needless in closing the subject of *nutrition*, to remind the student that the body derives no benefit from the food ingested unless the food is assimilated.

To be assimilated the food must be properly *digested*, then properly *absorbed* by the blood and lymph, and finally become part of the body-tissues. Then, too, to be a source of chemical potential energy, the absorbed food must be capable of *further oxidation*.

ANIMAL HEAT.

The **normal temperature** of the body is about 98.5° F. (37° C.). This temperature is not invariable, but in the superficial cavities, mouth, and axilla, which are convenient for ascertaining the body-temperature, this is nearly exact. In the internal organs the thermometer may indicate as high as 100° F. in normal conditions. In the rectum the temperature is about 1° F. higher than in the mouth or armpit. In health the temperature is maintained constantly with but slight variations, due to marked changes in surrounding air temperature, age, exercise, sex, etc. The temperature in health varies to the extent of 1° to 1.5° F., according to the time of day or night, being lowest late at night or in the early morning, while it is highest late in the afternoon. This corresponds to the usual temperature-ranges in fever, when the minimum is in the early morning, the maximum in the late afternoon.

Sources of heat: (1) Principally from the *oxidation of the tissues* during katabolism of the body-structure. The tissues of the body, as has been previously mentioned, are derived from the organic food-stuffs. Hence we owe our main supply of body-heat to the oxygen of the air and the organic food-stuffs.

(2) *Chemical action* going on *during digestion* of food is also productive of some heat.

(3) *Friction* of muscles upon one another, friction of blood in capillaries, and all forms of friction, are productive of a little heat.

(4) *Warm media about the body,* warm drinks and foods.

Of these various sources only the oxidizing of body-tissue generates enough heat to keep the body-temperature up to the standard. The main seat of this oxidizing is in the muscles, which form so large a part of the organism. Therefore, we can say that the principal part of the total heat produced within the body is generated by muscular activity. Active exercise may raise the body-temperature from 1° to 2° F.

Loss of heat: (1) *Blood circulating at the surface of the body* is cooled by the colder air. Although in ordinary health the external application of cold, as by baths, has only a slight effect on the temperature, it is otherwise in the case of high fever. In these cases a tepid bath may reduce the temperature several degrees, the effect lasting in some cases for many hours. This method of reducing high temperature is successfully applied in cases of sunstroke and certain fevers, especially typhoid.

(2) The *evaporation of sweat* dissipates a vast amount of heat.

(3) Loss of heat is considerable *by the lungs,* though less than that from the skin: the air is warmer, in usual conditions, after leaving the lungs than before it has entered them.

(4) *Warming the excretions* of the body (fæces, sweat, and urine) is another factor in loss of heat.

Regulation of heat: The amount of heat generated can be regulated by diminishing the source or increasing the elimination of heat, and *vice versâ.* The loss of heat is principally regulated by:

(1) The amount of blood sent to the surface to be cooled; this is regulated by the vaso-motor nerves; (2) the increase or decrease in sweat secretions. The supply of heat depends on the activity of tissue-metabolism, resulting from exercise, mental activity, etc.

Diseases, such as fevers, that are accompanied by a rise of temperature, owe that rise to either a marked increase in katabolism or diminished elimination power, or to both.

Centres for heat-regulation: There are reasons for believing that there are *nerve-centres* exciting the heat-production in the tissues (thermogenic centres), and centres which check the metabolism of tissue, and thus control the temperature (inhibitory heat-centres). This is not entirely proven, nor are these centres exactly localized. We do know that the innervation of a part is necessary for the maintenance of its warmth, aside from vaso-motor causes for alteration of temperature.

Limits of body-temperature: In ordinary pathological conditions the temperature does not remain long at a point below 95° F. nor above 105° F. without fatal results. Under extreme conditions of prolonged exposure to cold and the algid stage of cholera, recovery has occurred after a bodily temperature as low as 75° F. On the other hand, in some cases of extreme fever, as from sunstroke, recovery has been noted after a temperature of 110°–112° F.

Fig. 70.

Non-striated elementary fibres, from the human colon. *a*, treated with acetic acid, showing the corpuscles; *b*, fragment of a detached fibre not touched with acid.

MUSCLE.

Varieties: Muscle-tissue consists of three distinct types: 1. *Non-striated*, or plain muscle-fibre. This is "involuntary," or not under the control of the will.

2. *Striated muscle*, which is under the control of the will, or "voluntary."

3. *Striated muscle*, but not under the control of the will, hence "*involuntary*."

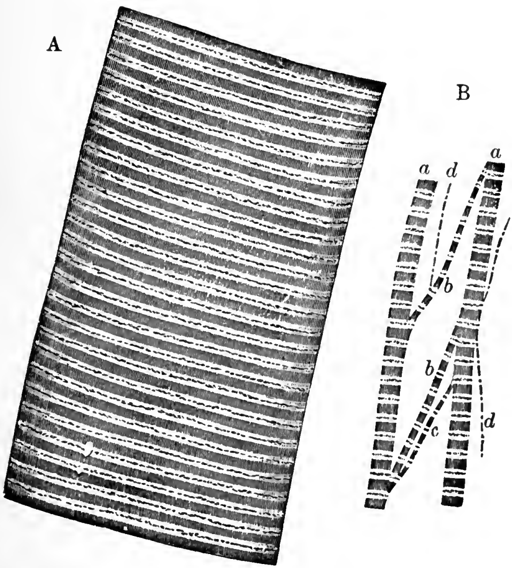
Examples of the first class are the muscles of the intestines, walls of the arteries, etc. The skeletal muscles make up the second class. The heart-muscle is the only example of the third class.

Microscopic appearances: *Non-striated muscle-tissue* is made up of bundles of elongated, spindle-shaped cells. Each cell has an oblong nucleus and is flattened (Fig. 70). In length they are about $\frac{1}{600}$th to $\frac{1}{300}$th inch, and about $\frac{1}{4000}$th inch in

width. The cells are bound into bundles by an albuminous cement, and these again into larger bundles by areolar tissue.

Striated voluntary muscle-tissue consists of bundles of long muscle-cells or fibres. Each fibre is completely enveloped in a sheath, the *sarcolemma*, and the whole bundle of fibres is bound together by a delicate connective-tissue framework.

FIG. 71.



A, portion of a medium-sized human muscular fibre (magnified nearly 800 diameters). B, separated bundles of fibrils, equally magnified: *a*, *a*, larger, and *b*, *b*, smaller collections; *c*, still smaller; *d*, *d*, the smallest which could be detached.

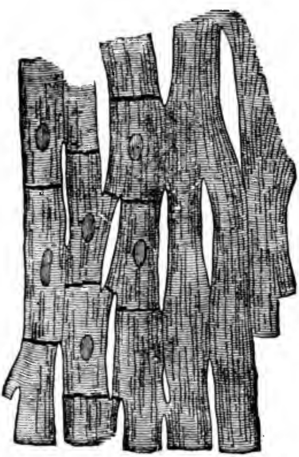
A number of these fasciculi are joined together to make up the gross anatomical muscle. On examining the *muscle-fibre* itself, it will be seen to consist of alternate segments of light and dark matter, giving the fibre a striped appearance (Fig. 71).

These fibres are about an inch in length and $\frac{1}{400}$th inch in diameter. They join the connective-tissue cells of a tendon

or aponeurosis or another muscle-fibre by adhesion of the sarcolemma at the ends, and thus unite the muscle-bundles in a firm mass; and this union is further strengthened by the cohesion of the fibres.

The striation of the *heart-muscle fibres* is not so marked as in ordinary muscle, and the form of the fibres is different, for they are branched and more slender. Each fibre is nucleated, a large oval nucleus occurring at the centre. The appearance of the heart-fibres indicates that they occupy an intermediate position between typical plain and striped fibres (Fig. 72).

FIG. 72.



Muscular fibres of the heart (Quain)

Muscle—general properties: (*a*) *Unstriated muscle-tissue* acts slowly, is not under the control of the will, acts continuously for quite long periods of time, and is slowly exhausted.

(*b*) *Involuntary striated muscle* (heart) acts quickly, is not under control of the will, acts for a short period, and recuperates rapidly. Under this condition of rapidly alternating periods of activity and repose, the heart-muscle does its work throughout the life of the individual.

(*c*) *Voluntary striated muscle* (skeletal) acts rapidly, is under control of the will, and recuperates quickly (but not so rapidly as heart-muscle).

Chemistry of muscle: About 75 per cent. of muscle-tissue is water. Proteids make up about 15 per cent. Of these, the chief constituent is myosinogen, which appears to bear the same relation to living muscle as fibrinogen does to blood. If by cold we delay the coagulation of muscles removed from animals immediately after death, we can express a viscid fluid of slightly alkaline reaction, known as *muscle-plasma*. This muscle-plasma, when exposed to ordinary temperatures, coagulates much in the same way as does blood-plasma, *myosin*

being formed. In a short time the clot will contract and squeeze out a fluid resembling blood-serum. Myosin differs from fibrin in many of its reactions. It belongs to the globulin class of proteids. Fat, glycogen, organic and inorganic salts (chiefly potassium) make up the remaining 10 per cent. The fat exists as minute strips between the fasciculi. The glycogen is stored up to serve as a supply of chemical potential energy. The amount of glycogen present in resting muscle is about $\frac{1}{2}$ per cent.

Physiology of muscle: Muscle may exist in three different conditions: those of *rest*, *activity*, and *rigor*.

Muscle-rest: During rest a muscle has a slight but very perfect elasticity. It can be stretched to a considerable extent, but always returns at once to its former condition. In the living body the muscles are always in a condition of slight tension, which gives mechanical advantages. Even during a state of rest the muscle takes oxygen from the blood and gives up carbon dioxide to it. The reaction of a resting muscle is neutral or faintly alkaline.

Muscle during activity: The peculiar property of muscle-fibre is its contractility, which is excited by all kinds of stimuli direct and indirect. This property is soon lost, unless the supply of arterial blood is kept up. Muscles, especially the striated, possess a certain kind of sensibility due to the sensory nerve-fibres which end in them. They are but slightly sensible to pain, the sensations produced being rather those of the condition of the muscle, as to fatigue, cramp, etc.; or else of muscular sense, as to position of the muscles, comparison of weights, etc.

After activity the reaction is acid, due to the development of sarcolactic acid or lactates by the breaking up of the glycogen in the muscle. There is also an increase in water and carbon dioxide.

Only a little proteid material is oxidized during muscular activity. This is shown by the fact that after severe exercise the amount of urea excreted, although increased somewhat, is not increased commensurately with what would have been the case had the proteid furnished the chemical potential energy.

Actions of muscles as levers: Most of the voluntary muscles in the body may be regarded as sources of power for moving the bones viewed as levers. All levers are divided into three classes, according to the relative position of the power, the weight to be moved, and the axis of motion or fulcrum. The different movements of the foot offer an illustration of all three kinds of levers: The *first kind* (Fig. 73),

FIG. 73.

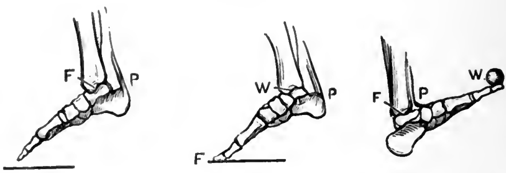


Illustration of levers of all three orders (Huxley).
W, weight of resistance; F, fulcrum; P, power.

where the fulcrum, F, is between the source of power, P, and the weight or resistance, W, is illustrated when the foot is raised and the toe tapped upon the ground, the ankle-joint being the fulcrum. The *second kind* of lever, where W is between F and P, is illustrated when the body is raised upon the toes, the ground being the fulcrum. The *third kind* of lever, where P is between F and W, is illustrated when a weight is held up by the toes, the ankle being the fulcrum and the anterior group of muscles on the leg the source of power. The forearm also acts as a lever of this sort when a weight is lifted in the hand.

Oxygen-supply: Muscle receives its oxidizing agent—oxygen—from the blood coursing through the vessels contained in the muscle. Even during repose the muscle takes up oxygen from the blood and gives back carbon dioxide. The muscle also stores up within itself a certain amount of oxygen, which can be called upon to do work even if the blood-supply be stopped. To prove this it is only necessary to cut a muscle out of the body and cause it to contract in a chamber of nitrogen. As a result of these contractions the muscle

throws off a quantity of CO_2 as a product of oxidation. The oxygen necessary for this oxidation comes from the supply stored up in the muscle as the only source, there being no blood-supply and the atmosphere of the chamber in which the experiment is conducted consisting only of nitrogen.

During muscular activity a greater supply of oxygen is needed, and this is supplied by a dilatation of the bloodvessels of the part. Systematic exercise of a muscle educates the arterioles supplying that muscle to remain in a condition of dilatation. This increase in the blood-supply not only provides an increase of oxygen during activity, but during repose carries an increased amount of nourishment to the muscle, with the result that the muscle increases in size and power. Hence the value of "training."

Muscle-fatigue: After performing its function of contraction for a certain length of time the muscle is less active in its response to stimuli, and finally, in spite of the strongest impulses, fails altogether to act. This is "fatigue" of a muscle, a phenomenon with which we are all familiar. After a suitable rest the muscle recuperates and is as active as ever.

The reason for this fatigue is that during the muscle's activity a number of effete poisonous products, the result of the active katabolism, have been formed more rapidly than the power of removal by the outgoing blood. After a time the accumulation of poison is so great as to paralyze the muscle, so that no further activity takes place until the excess has been removed.

The first effect of fatigue is seen in the increased latent period and decrease in the strength of the contraction.

Muscle—latent period: By latent period is meant the time that elapses after a stimulus has been applied to a muscle and before the muscle acts.

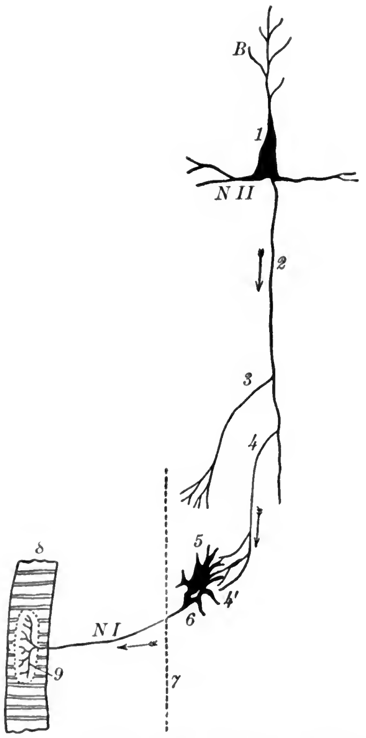
We speak of the "apparent" latent period and the "true" latent period.

By *"apparent" latent period* is meant not only the time consumed by the impulse in awakening the muscle into activity, but also the time consumed by the impulse in reaching the muscle (say in travelling along the nerve).

"True" latent period is the actual time consumed between

the arrival of the impulse at the muscle and the beginning contraction. The time for the true latent period is about one one-hundredth of a second.

Fig. 74.



Diagrammatic representation of cerebral and spinal motor cells with axons. 1, cerebral cell; 2, axon; 3, 4, collaterals; 4', end-tufts; 5, spinal cells; 6, axon; 7, limit of spinal cord; *NI*, motor-nerve; S, muscle; 9, muscle end-plate (Rauber).

Contractility: The important use of this power is to do "work"—*i. e.*, the conversion of the potential chemical energy of the muscle into heat and visible motion.

If one watches a muscle contract, he will see that the muscle becomes much thicker and shorter; but the volume does not change. The fact that there is *no change of volume* during contraction may be proved by placing a muscle in a vessel filled with fluid to a given mark. The muscle is now made to contract, and it is noted that the level of the fluid remains unchanged.

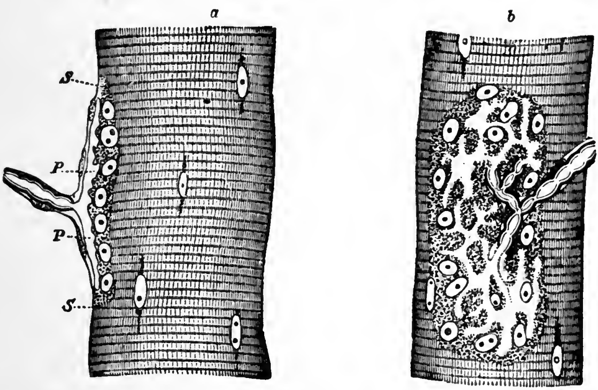
Owing to the increased metabolism during functional activity, there is heat liberated, hence an increase of temperature.

Path of stimulus for contraction: In the living body the impulse causing contraction of a muscle arises in the centres of brain or spinal cord, and travels thence by means of anterior nerve-roots and the somatic nerves going to the particular muscle (Fig. 74). The nerve that supplies a given muscle as it enters that muscle breaks up into a num-

ber of branches that are distributed to all parts of the muscle. The terminal ends of the nerve-fibres are small cellular elements called nerve end-plates or end-organs (Fig. 75). As a rule, these end-organs are scattered in great numbers throughout the muscle. By means of these end-plates the impulse from the nerve is transmitted to the muscle-fibres.

Contractility an inherent property of muscle: Although under ordinary circumstances an impulse to contract is sent to a muscle through the intervention of its nerve and end-plates, nevertheless the impulse may be administered directly to the muscle itself and the result be a contraction.

FIG. 75.



Nerve-ending in muscular fibre of a lizard (lacerta viridis). *a*, end-plate seen edgeways; *b*, from the surface; *s*, *s*, sarcolemma; *p*, *p*, expansion of the axis-cylinder. In *b* the expansion of the axis-cylinder appears as a clear network branching from the divisions of the medullated fibre. Highly magnified (Kuhne).

To prove that a stimulus may be administered directly to muscle-fibre with a resulting contraction the following experiment will be described:

Liberate the sciatic nerve from the surrounding tissues in the thigh (say the right) of a frog; but do not destroy the connection of this exposed nerve with the gastrocnemius muscle or the spinal cord. Pass a ligature about the right thigh so as to include all the tissues except the sciatic nerve. Tie the ligature tightly. The purpose of this ligature is to shut

off all blood-supply to the lower part of the limb. Now poison the frog with curare. Curare is the Indian arrow-poison, and kills by paralyzing the end-plates in all the muscles. In the frog experimented upon, the poison is carried to all parts of the body except to the right leg below the ligature. The frog lies as though completely paralyzed.

Now, with an electrical battery stimulate the right sciatic nerve; the right gastrocnemius contracts. Stimulate the *left* sciatic; no result. During the stimulation of both the right and the left sciatics the nerves showed that they were carrying impulses (proven by a galvanometer); hence the lack of activity in the left leg is due to the curare having affected either the muscle itself or the end-organs. On the right side the blood carrying the curare has been prevented (by the ligature) from reaching the muscle or its end-plates.

Now apply the electrical stimulus directly to each gastrocnemius in turn; both will be found to contract and with equal vigor.

This experiment proves the following facts: (1) Curare paralyzes a muscle by inhibiting the end-plates of the nerves; hence (2) the nerve-endings in the left gastrocnemius being paralyzed, the stimulus that made the left gastrocnemius contract necessarily exerted its influence *on the muscle direct*, and not by the intervention of the end-plates.

Another proof may be offered to the same end, as follows: the gracilis muscle in the frog is practically free from nerve end-organs in its lower part, and yet the lower part of the muscle contracts as readily to direct stimulation as does any other muscle. An additional proof is that the heart of the embryo begins to beat some time before the nerve end-organs have developed within the heart-muscle.

Artificial stimuli: A muscle may be stimulated to activity either by irritating the muscle itself, or by sending impulses to the muscle through the intervention of its motor nerve.

The stimuli employed are: (1) chemical, (2) mechanical, (3) thermal, (4) electrical. The last (electrical) is the most practical and most frequently used.

To study the effects of muscular contraction a *myograph* is necessary. A myograph consist of a drum or cylinder cov-

ered with smoked paper. The drum is made to revolve by clockwork at a definite rate. The nerve-muscle preparation is so arranged that when the muscle contracts a lever is made to trace a curve on the smoked paper. This curve is called a *myogram*, and by studying the curve one can learn the amount and character of the contraction.

Galvanic, faradic, and interrupted currents: A *galvanic current* is a continuous flow of electricity directly from the battery.

A *faradic current* consists of a direct current passing through a coil of wire; about this coil is wrapped a second coil, carefully insulated from the first coil. The current passing through the primary coil, induces a current in the secondary coil. It is the secondary current that is applied to the nerve to be experimented upon.

An *interrupted* or *alternating current* is a faradic current in which the primary current is rapidly made and broken by an automatic interrupter.

Response to stimuli: It has been found that striped and unstriped muscles react to stimuli in a somewhat different manner. This difference is probably due, for the most part, to their differing structure, but may possibly be due in some degree to their differing modes of connection with the nervous system. When a stimulus is applied to a striped voluntary muscle there is an instantaneous contraction of the part irritated, and of that only. This contraction ceases the moment the stimulus is withdrawn. If, on the other hand, any part having involuntary muscle—for instance, the bladder or intestines—is stimulated, the contraction comes on more slowly, extends beyond the part stimulated, and continues for some time, with alternating relaxation, after the stimulus is withdrawn.

Effect of galvanic shock: The instantaneous application and removal of a galvanic shock to a nerve-muscle preparation result in a single twitch of the muscle. Although it is stated above that the application is "instantaneous," it is shown by experiment that the impulse is not appreciated by the nerve unless the flow of current lasts at least 0.0015 of a second. On examining the curve traced by the muscle on the myo-

graph, there are noted: (*a*) the *latent period—i. e.*, the time elapsed after the application of the current before the con-

FIG. 76.

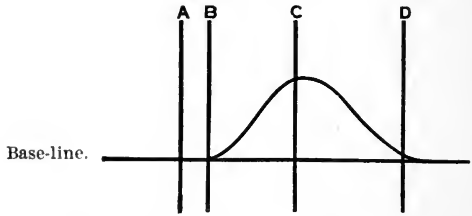


Diagram of muscle-curve. *a*, point of application of current; *b*, point of beginning contraction; *c*, maximum; *d*, return to normal.

traction commenced; (*b*) a *gradual rise* in the curve until the maximum is reached, and then a gradual curve down to the base-line (Fig. 76).

FIG. 77.

Opening shock.

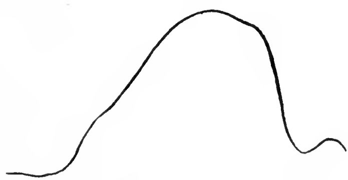
The time *a-b* is the latent period, and in the case of a frog's gastrocnemius is about $\frac{1}{100}$th of a second. The total curve in the same muscle lasts about $\frac{1}{10}$th of a second.

If, instead of applying and removing the galvanic current in close succession, the current be allowed to flow for some

time through the nerve-muscle preparation, two contractions and relaxations are noted. One contraction and relaxation takes place when the current is applied, but during the rest of the flow of the current the muscle remains in a state of repose. The *second* contraction and relaxation occurs when the current is broken. The contraction at the "make" of current is greater than that at the "break" (Figs. 77 and 78).

From the fact that the muscle remains quiescent during the flow of the current after the first shock, the theory is deduced that it is not the change in state, but the *rapidity* of the change in state, which irritates the muscle into contraction. This is proven by the fact that a large amount of electrical current can be poured into a nerve-muscle preparation without exciting a contraction, provided the current be gradually applied and very slowly increased. On the other hand, a small amount of electricity if rapidly administered will produce a sharp contraction.

Fig. 78.



Closing shock.

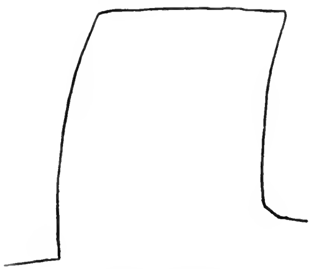
Induced current: A *single shock* from an induced current produces the same result as that of a galvanic current of instantaneous duration.

A *prolonged application* of the induced current produces the contraction on the "make" and a contraction on the "break" similar to that of the galvanic current, except that the "break" contraction is greater than the "make" contraction.

Interrupted current: The interrupted current, consisting as it does of rapidly alternating "makes" and "breaks," produces a series of rapidly succeeding shocks on the nerve-muscle preparation. The result is that the muscle, after the period of contraction is over, has no time to relax before a second shock is received, which tends to a fresh contraction. Hence the muscle remains in a state of continuous contraction until the stimulus is removed or the muscle wears out. This condition of continuous contraction is called *tetanus* (Fig. 79).

Muscle—electrical state: By a rise in electrical state is meant an increase in the height of the curve in succeeding contractions, on the application of single shocks. It is as though the muscle became more sensitive and more responsive to the second shock than to the first, and more so to the third than to the second, etc. This rise in electrical state is observed for the first six to ten shocks. It is as though the muscle "limbered up" in the first few shocks by a little preliminary exercise until it reached its power of doing its best.

Fig. 79.



Curve of tetanus.

Currents of rest: When a living muscle is tested by means of the galvanometer after removal from the body, it is found to develop certain electrical currents known as *muscle-currents* or *currents of rest.* They are strongest from the centre of the muscle toward the cut end, though certain minor currents are developed with the electrodes in closer proximity. The cut ends of a muscle are always electro-negative to its equator. This phenomenon cannot be observed in uninjured muscle when in the body, but any injury will render the injured portion electro-negative to the rest of the muscle. This condition ceases with the power of contraction, and cannot be demonstrated in dead muscle.

When the muscle is made to contract, the galvanometer-needle, which has indicated the passage of an electrical current during rest, flies quickly back toward the zero, indicating the cessation of the current of rest. This action is known as the *negative variation* of the galvanometer, and as soon as the contraction of the muscle has ceased the instrument again indicates the presence of the current of rest.

The *causes* are not yet fully determined, but these currents are probably due to chemical changes resulting from physiological degeneration. It has been held that such

currents occur naturally in muscle as the result of certain of the cells exciting electro-motive forces, but the former theory seems the more plausible.

Excitability and conductivity: These terms, although similar as to the results, really mean very different things.

Excitability, or *irritability*, refers to the activity of response a nerve may show to a given electrical shock; whereas *conductivity* means the power of one part of a nerve to conduct an impulse generated at another part of the nerve.

A moderate current while passing through a nerve produces no shock, but the excitability of the nerve at the point where the kathode is placed is increased (this increase at the kathodic area is called katelectrotonus); at the same time the excitability of the anodic area is lessened (anelectrotonus). On *removing* the current the excitability at the kathodic area falls, and the excitability at the anodic area rises.

On the other hand, during the flow of a moderate current there is a marked diminution in the *conductivity* of the nerve at the kathodic area, even to the extent of rendering the kathodic area impervious to conduction, without seriously affecting the anodic area. On removing the moderately strong current the nerve instantly returns to its normal conductivity. If very strong currents be used, conduction is completely lost at both the anodic area and the kathodic area during the flow of the current; and when the current is removed the nerve does not at once return to a normal state of conductivity, but remains impaired for a little while.

Pfluger's law of contraction: It has already been shown that the stimulation of a nerve-muscle preparation by a galvanic current will result in a contraction only at the "make" and at the "break" of the current; this is true only if the current be of medium strength, regardless of whether the current be "ascending" or "descending." But the results are different if the current be very weak or very strong.

The following table, known as Pflüger's table, shows the effects at a glance:

Current-strength.	Ascending current.		Descending current.	
	"Make."	"Break."	"Make."	"Break."
Weak current	Contraction.	. . . .	Contraction.	. . . .
Medium current . .	Contraction.	Contraction.	Contraction.	Contraction.
Strong current . . .	. . . .	Contraction.	Contraction.	. . . .

Ascending and descending currents: By an *ascending current* we mean a position of the electrodes such that the electrical flow is from the periphery (muscle) to the centre (brain) —*i. e.*, the anode or positive pole is nearer the muscle and the kathode or negative pole is nearer the nerve-cell. The *descending current* is the reverse and the poles are transposed.

The *explanation* of the results is simple, if we bear in mind the effects on the nerve of the various strengths of currents.

A galvanic current is stronger on the "make" than on the "break." Hence if we reduce the strength of our current so that the "break" shock is so weak as to fail to give any result, our "make," being somewhat stronger, would still influence the muscle so as to cause a contraction. This, too, would be regardless of the direction of the current. This explains the first part of the "law," namely, that regarding weak currents.

In explaining the *second* part of the law, it is necessary to bear in mind that the nerve-vibrations start from the region of the kathode on closing the current; but on opening the current the nerve-vibrations start at the anodic area; also to bear in mind that moderate currents diminish the conductivity at the kathodic area without affecting the anodic region, and on removing the current the nerve at once returns to normal.

So we find on closing a descending current of moderate strength, the excitation starting at the kathode can readily pass to the muscle and produce a contraction. On opening the current, the excitation starts at the anode and readily travels along the nerve past the kathodic area (which, on opening the current, returned to normal conductivity), and so on to the muscle.

If we take an ascending current, on closing, the impulse

goes from the kathode down the nerve, past the unaffected anodic area, to the muscle. On opening the current, the impulse passes from the anode directly to the muscle.

For the *third* part of the law we must remember that very strong currents reduce conductivity at both anode and kathode, and on removing the current the loss of conductivity does not at once disappear. So, to study it in detail, let us assume a strong ascending current. On making the current we remove the conductivity of the anodic area, and the impulse starting at the kathode cannot travel by the impervious anodic area, and hence no contraction results. On opening the current the impulse from the anode passes to the muscle and a contraction follows. With a descending current, we find on closing that the impulse starting from the kathode travels to the muscle unhindered and a contraction results; but on opening the current the impulse starting at the anode travels along the nerve until it reaches the area where the kathode was. This area the impulse cannot pass (for the conductivity does not return for some time) and no contraction results.

Position in the body: During repose a muscle is not in a state of complete relaxation, but in an intermediate condition between relaxation and contraction. The object of this is to save time; for the muscle can at once exert its power, as it has no "slack" to gather in before it exerts its pull. Also there is no jerk or jar in the motion.

Results of contraction: (*a*) heat; (*b*) motion; (*c*) sound; (*d*) change of shape; (*e*) fatigue; (*f*) chemical changes; (*g*) rise of electrical state.

Nerve-muscle preparation—conditions influencing the results: (*a*) freshness of the nerve-muscle preparation; (*b*) suitable temperature (98.6° F.) and moisture; (*c*) suitable stimulus—interrupted electrical current; (*d*) moderate weight for the muscle to act on; (*e*) duration of stimulus—not less than 0.0015 of a second; (*f*) position of electrodes—they must be applied to the nerve obliquely and not at right angles; (*g*) a suitable length of nerve must intervene between the two electrodes.

Nerve-muscle preparation—order of fatigue: Fatigue appears in a nerve-muscle preparation: first, in the nerve-

endings; second, in the muscle-fibres; third, in the nerve proper (practically untiring).

The following experiments are offered in proof of the above statement:

Stimulate a nerve-muscle preparation through the nerve until the muscle no longer contracts. Then apply the stimulus to the muscle-substance directly; it is noted that the muscle is excited to still further activity. This shows that either the nerve or the nerve-endings were exhausted before the muscle itself. To determine which is more liable to give out, nerve or nerve-endings, perform the following experiment:

Poison a nerve-muscle preparation with curare, which, as has been shown elsewhere, inhibits the action of the nerve-endings. Now, while the nerve-endings are paralyzed, apply a continuous stimulation to the nerve-fibre. No muscular activity is seen, for the stimulus cannot pass from the nerve to the muscle across the bridge of poisoned end-plates. Nevertheless the nerve is being constantly stimulated. After a time the effects of the poison pass off and the end-plates recover their activity, and the stimulus which is applied to the nerve is transmitted to the muscle and active contractions follow. This shows that the nerve outlasts either the end-plates or muscle, for the nerve has been receiving and has been capable of transmitting stimuli during the entire stimulation, a period of time far greater than that during which either the end-plates or muscle-fibre would have been capable of such activity.

From these two experiments we deduce the order of fatigue —(1) nerve-endings, (2) muscle, (3) nerve-fibre. It is also shown that nerve-fibre is practically untiring.

Rigor mortis: When an animal dies the muscles of the body do not die at once, but remain alive for a variable time. In man, if the individual be wasted and enfeebled by long illness and disease, the muscles may die in about ten minutes after the death of the individual. In robust, healthy people suddenly killed, the muscles may live for six or eight hours longer. All the intermediate stages have been noted. The death of the muscle is characterized by a contraction, fixing

the limbs and body in a rigid condition. This post-mortem rigidity constitutes *rigor mortis.* The muscles of the jaw and neck are usually first affected, and then the arm, trunk, thighs, and legs in the order named. All muscles are affected, both the voluntary and involuntary.

The condition of rigor mortis lasts from ten to twenty-four hours, and passes off in the inverse order from its appearance. First the legs relax, then the thighs, etc., and lastly the jaw.

Cause of rigor mortis: Rigor mortis is caused by a fermentative change which produces a coagulation of the blood-plasma in the muscles. During this coagulation-process there is a development of heat, which causes a rise in the temperature of the body. It may amount to 5° or 10° F., or even more.

Cause of disappearance of rigor mortis: After the fermentative change which causes the coagulation of the muscle-plasma has ceased, a putrefactive process is set up which destroys the coagulum and the muscles become soft and flabby.

NERVOUS SYSTEM.

Fibres and Cells.

The **nervous system** is an aggregation of tissues so arranged as to adjust the workings of all the parts of the body to one another and to suit the body to its environment.

The elementary tissues of the nervous system are of two forms: nerve-fibres and nerve-cells.

The **nerve-fibres** are of two kinds: (1) medullated or white fibres; (2) non-medullated or gray fibres. The fibres are united in bundles to form nerve-trunks or "nerves."

The **cells** are in groups to form nerve-ganglia, but nerve-fibres are also found in the ganglia.

Medullated fibres consist of (1) an external nucleated sheath, or *neurilemma;* (2) an inner protective *medullary sheath* (the white matter of Schwann); and (3) internally the *axis-cylinder* (Fig. 80).

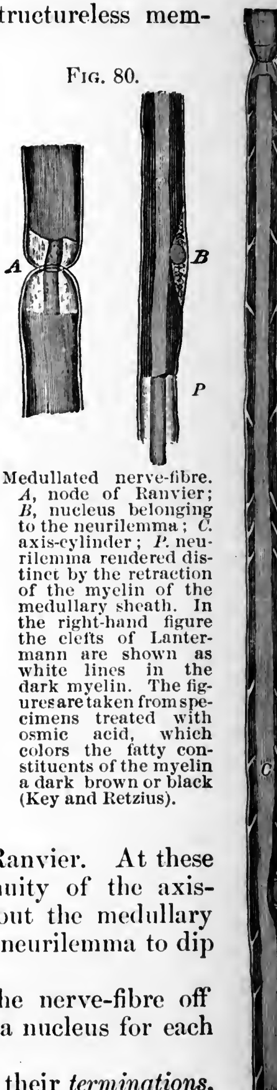
The *neurilemma* is a pellucid structureless membrane. Within are seen at intervals *nuclei* surrounded by more or less protoplasm. These nuclei and their protoplasm are relics of embryonic cells.

The *medullary sheath* is a thick fatty semifluid substance. It is this substance which produces the peculiar white appearance of some nerves. Some authorities have claimed that it is made up of a fine network, in the meshes of which is embedded the bright fatty material.

The *axis-cylinder* consists of a large number of primitive fibrillæ which vary considerably in size, but on the average may be said to be about $\frac{1}{1500}$th inch in diameter. There is little doubt that the axis-cylinder is the essential part of the fibre, the other parts being merely for support or protection.

Nodes of Ranvier: Here and there at short intervals along the course of medullated fibres are found notches or constriction in the medullary sheath. These constrictions are called the nodes of Ranvier. At these points there is no loss of continuity of the axis-cylinder nor of the neurilemma, but the medullary sheath is deficient and allows the neurilemma to dip in and touch the axis-cylinder.

FIG. 80.



Medullated nerve-fibre. *A*, node of Ranvier; *B*, nucleus belonging to the neurilemma; *C*. axis-cylinder; *P*. neurilemma rendered distinct by the retraction of the myelin of the medullary sheath. In the right-hand figure the clefts of Lantermann are shown as white lines in the dark myelin. The figures are taken from specimens treated with osmic acid, which colors the fatty constituents of the myelin a dark brown or black (Key and Retzius).

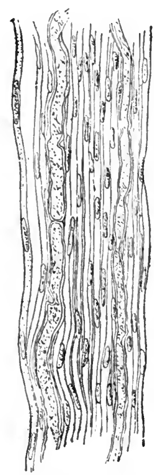
The nodes apparently divide the nerve-fibre off into histological units, for there is a nucleus for each segment marked off by the nodes.

As the medullated nerves near their *terminations,*

the medullary sheath disappears and the axis-cylinder continues with the neurilemma; but this latter also disappears before the final ending of the fibre (axis-cylinder) in the tissues. The fibre then splits into two or more terminal branches. Thus white fibre becomes non-medullated fibre.

Non-medullated fibres: They consist of the axis-cylinder alone, without the medullary sheath. They do not differ in any other regard from the white fibres. When collected in bundles to form nerves they have a yellowish or grayish color. They are found in the olfactory and auditory nerves and in the nerves of the sympathetic system, and they occur in greater or less number in the nerves of the cerebro-spinal system. In size these fibres are about one-third to one-half the diameter of the medullated. They are sometimes spoken of as the *fibres of Remak* (Fig. 81).

FIG. 81.



Fibres of Remak; magnified 300 diameters. With the gelatinous fibres are seen two of the ordinary, dark bordered nerve-fibres (Robin).

Formation of nerve-trunks: To build up a nerve-trunk, whether from medullated or non-medullated fibres, the fibres are joined in bundles which are enclosed in a thin fibrous sheath (perineurium), and these bundles of nerve-fibres are bound in a firm connective-tissue which serves to protect and to unite them strongly. So far as we can see, the individual nerve-fibres, as a rule, are continuous and independent from their origin in the nervous centres to within a short distance of their peripheral termination. When a nerve divides into several branches, or when adjacent nerves communicate, it is because certain fibres leave those with which they are associated and pursue a different course. There is no real union of nerve-fibres.

Function of nerve-fibres: The function of a nerve-fibres is the transmission of a stimulus. The axis-cylinder connects the centre and periphery cells, and conveys between them the stimuli. This

transmission for any particular fibre is in one direction only.

Depending on the direction the impulse is carried, the nerve-fibres are classified into afferent (or centripetal), efferent (or centrifugal), and intercentral fibres.

The former are those by which impressions are taken from the periphery to the brain, and are commonly called *sensory* fibres.

Conduction in these nerves may cause (1) a sensation as of pain, heat, etc.; (2) special sensation; (3) reflex action of some kind; or (4) inhibition or restraint of action.

The *second* class conduct stimuli to the periphery, and are known as *motor* fibres. Conduction in these nerves may cause: (1) contraction of muscles (motor nerves); (2) control of nutrition (trophic nerves); (3) control of secretion (secretory nerves; or (4) inhibition, augmentation, or checking of other efferent impulses.

The *last* class includes nerve-fibres which connect more or less distinct nerve-centres, and may therefore be said to have no peripheral distribution. Nerve-fibres are mere conductors of impressions. An impulse started in any fibre is transmitted unchanged to its termination without being imparted to any of the fibres lying near it.

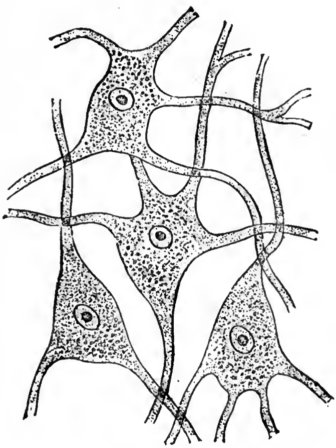
Nerve-cells: As has been shown, the nerve-fibres are the conveyors of impulses, either from the brain to the periphery, or from the periphery to the brain. It is now in order to study the termination or starting-points of these impulses. Every nerve-fibre starts or ends in a nerve-cell, which is the origin of the impulse in the case of an efferent nerve-fibre, or the recipient of the sensation in afferent nerves.

Nerve-cells or ganglion-cells present a great variety of shapes, and yet have common characteristics. The cell-body is granular, and contains a large nucleus which contains a prominent nucleolus. The cells have at least one process, and often more (Fig. 82), and the cells are classified as unipolar, bipolar, or multipolar. These processes are of two kinds —one kind dividing and subdividing (*branching* or *protoplasmic processes;* or dendrites) until they become very delicate and seem to interlace with, but without joining, the

equally fine processes from other cells; another kind (*axis-cylinder processes* or *axons*) pass on without division and become axis-cylinders of medullated nerve-fibres.

The nerve-cells vary greatly in size, and are very diverse in form, but the presence of a nucleus, a nucleolus and the processes is characteristic of nerve-cells. They may be

FIG. 82.



Nerve-cells from the anterior horn of the gray substance of the spinal cord.

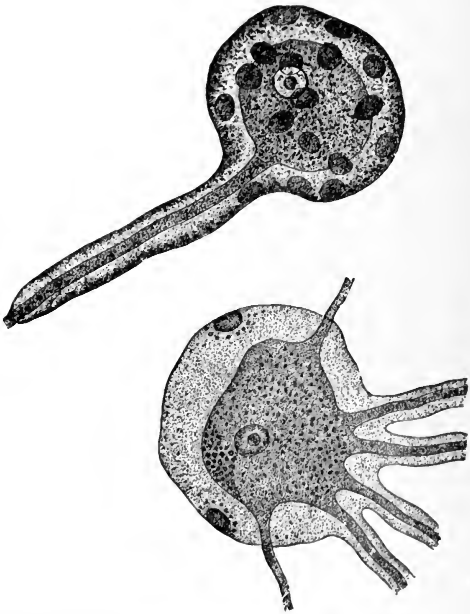
enclosed in a delicate capsule, which becomes continuous with the neurilemma (Fig. 83).

Nerve-endings at periphery: *Efferent nerves*, as has been stated previously, on nearing their terminations undergo a loss of the neurilemma and the sheath of Schwann, the axis-cylinder itself splitting into several subdivisions. Each of these subdivisions ends directly in the substance of a cell belonging to the organ supplied, by means of end-plates.

Sensory nerves "ending" in the skin find their way to or take origin from certain bodies (sense-organs) which are essential to the conduction of the sensory impression to the central nerve-ending. These sense-organs are of several kinds. In

the fingers and toes are found two kinds of sense-organs which may be especially mentioned: 1, touch-corpuscles

FIG. 83.



Nerve-cells, from spinal and sympathetic ganglia of man, enclosed in their capsular sheaths—from hardened preparations (Key and Retzius).

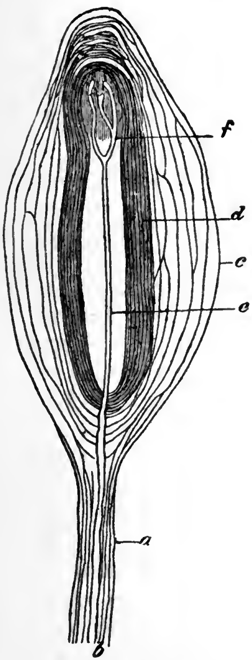
(Fig. 85); 2, Pacinian corpuscles (Fig. 84). The exact anatomy and physiological use of these bodies are still somewhat obscure; and, indeed, the whole subject of sensory nerve-terminations is but ill understood. We may regard the fibres of sensory nerves, as a majority, as forming a minute plexus in the corium and to terminate in sense-organs in a way not always known. Some of the special sense-organs are possessed of nerve-endings which are more clearly observed.

Neuron: By the term neuron (Fig. 86) is meant a nervous

entity—that is, a nerve-cell, its axis-cylinder process, dendrites, and the terminals.

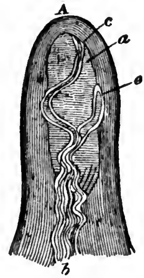
Nature of nerve-impulse: The nature of the impulse that travels along the nerve is hard to determine. Nerve-fibres

Fig. 84.



Vater's or Pacini's corpuscle. *a*, stalk; *b*, nerve-fibre entering it; *a*, *d*, connective-tissue envelope; *e*, axis-cylinder, with its end divided at *f* (Quain).

Fig. 85.

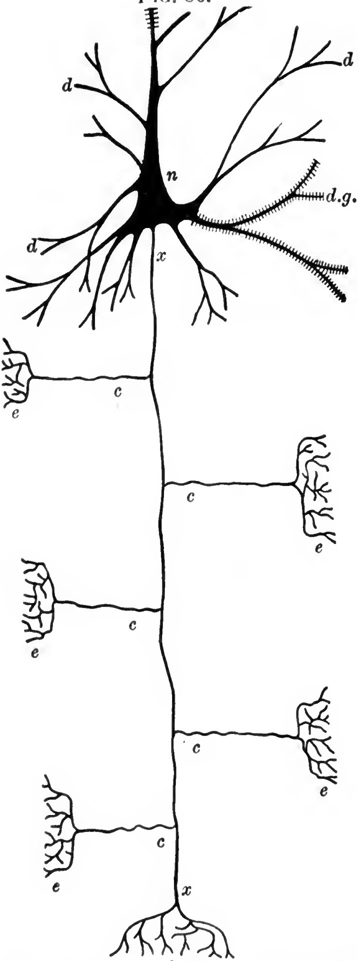


A, tactile corpuscle; *b*, nerve (Quain).

may be stimulated by anything which increases their irritability with sufficient suddenness, but they cannot of themselves originate such a condition. The stimulus produces its effect upon the nerve-termination. The result, therefore, of any stimulation of a nerve depends solely on the character of the end-organ, and not upon the character of the stimulus.

Artificially in a nerve-muscle preparation the impulse can be aroused by four methods: chemical, thermal, electrical, and mechanical means. The impulse passing along the nerve is not chemical, because there is no heat liberated; nor is there an expansion of nerve-fibre, even after prolonged activity, and naturally one would expect heat and expansion as the result of chemi-

Fig. 86.



Neuron with long axon proceeding as an axis-cylinder of a nerve-fibre. *n*, nerve-cell proper; *d*, dendrites; *x*, axon; *d. g.*, dendrite showing gemmulæ; *c*, collaterals; *e*, end-tufts or terminals. Pyramidal cell of the cerebral cortex (S. Ramon y Cajal).

cal changes. The fact that the nerve does not change its temperature excludes the thermal theory.

The impulse cannot be an electrical one, because there is no insulation for the conductors (the nerves).

The best explanation of the impulse is that probably it is a physical molecular vibration.

Direction of nerve-impulse: A nerve-impulse may travel in either direction in a given nerve, be it either afferent or efferent; but the impulse travelling in the physiological direction alone is manifest, because the impulse travelling in the physiological direction is the only one that finds suitable terminals through which to become manifest.

It can be shown that a nerve-fibre is capable of transmitting its impulse in either direction by the following experiments:

1. Take a fresh nerve of considerable length, and apply near its middle the two poles of a galvanometer. Apply a suitable stimulus to one end of the nerve; an impulse will be generated which will travel

along the nerve. The presence of the impulse will be detected by the galvanometer. This change of electrical state, due to the physical molecular vibrations and shown by the galvanometer, is called the "current of action." The galvanometer has now shown that the nerve has carried an impulse in one direction. If now we apply the stimulus to the opposite end of the nerve, the galvanometer again will record a "current of action," thus showing an impulse travelling in the opposite direction to that taken by the first impulse.

2. If one were to stimulate one of the *terminal branches* of an efferent axis-cylinder, not only would the impulse travel in the physiological direction toward the end-organ, but the impulse would travel up the branch of the axis-cylinder until it reached the point where the axis-cylinder had divided, and then travel down the other branches to their respective end-organs.

Speed of nerve-impulses: Efferent impulses are somewhat slower than afferent, the rate for the former being about 110 feet per second; for the latter, about 150 feet.

The time occupied in executing a voluntary movement at a given signal—for instance, the recording the time of a transit in an astronomical observation—is found to be sufficient to demand a correction for an accurate result. This amounts to $\frac{1}{4}$ to $\frac{1}{50}$ of one second with different individuals. The time lost in this way is known as the *personal error* of the observer. When this has been ascertained by experiment, the allowance to be made for the personal error is his *personal equation*. This remains nearly constant for each person.

Degeneration: When a nerve is divided its function, of course, ceases. It is no longer capable of carrying impulses throughout its length, owing to the loss of continuity. But by applying proper artificial stimulation to the nerve at a point distal to the point of division in the case of an efferent nerve, or proximal to the cut in an afferent nerve, a response is obtained similar to the normal action. For example, certain muscles may be made to contract by applying an electric shock to the distal end of a cut motor nerve; or sensation of pain may be produced by stimulating the proxi-

mal end of a sensory nerve. Furthermore, it is noticed that for the first few hours after division the irritability of a divided nerve is heightened; after this period of heightened irritability the nerve begins to lose its power of conductivity, and in three or four days the process of degeneration is complete and the nerve fails to convey any impulses.

Microscopic examination: When examined under the microscope a divided nerve-fibre presents certain changes. At the point of division, degeneration takes place in but one direction, and that away from the "nutrient cell," or cell of which it was an outgrowth. The degeneration of the fibre extends to its final distribution. In the case of a medullated nerve-fibre, if the section is at a point between two nodes of Ranvier, the degeneration in that portion of the nerve still in continuity with its trophic cells extends up as far as the first node of Ranvier from the point of section.

The histological changes during the period of degeneration are as follows: During the period of increased irritability the axis-cylinder is slightly granular, and the medullary substance somewhat cloudy. Soon a complete fragmentation of the axis-cylinder takes place, the myelin-substance is destroyed, the axis-cylinder is absorbed, and in place of the normal nerve only the neurilemma is left.

Non-medullated fibres have not been studied with such great care, but the process of degeneration is the same as that described, except for the absence of a medullary substance.

The degeneration occurs practically simultaneously throughout the entire portion of the nerve involved.

Nerve-regeneration: If, under proper precautions, the severed ends of a divided nerve are put in apposition, they may be made to unite and regenerate, with a return of function. It is noticed that sensory fibres regenerate more rapidly than motor—*i. e.*, in the case of an ordinary mixed somatic nerve during regeneration pain is felt before motion is present.

Microscopic examination shows an extension of the axis-cylinder from the normal part of the nerve into the empty neurilemma of the degenerated portion. The regenerating axis-cylinder extends along until it reaches the final distribu-

tion of the nerve, the medullary substance gradually being reformed, until the nerve is again intact.

Although the **nervous system** throughout the body is connected with the brain and forms an integral whole, nevertheless it has always been the custom to speak of a certain portion of the nervous system as a separate part, to which the name "**sympathetic system**" has been given, the rest of the nervous system being designated as the **cerebro-spinal.**

The **cerebro-spinal system** consists of the brain, the medulla oblongata, and the spinal cord, with the nerves proceeding from them.

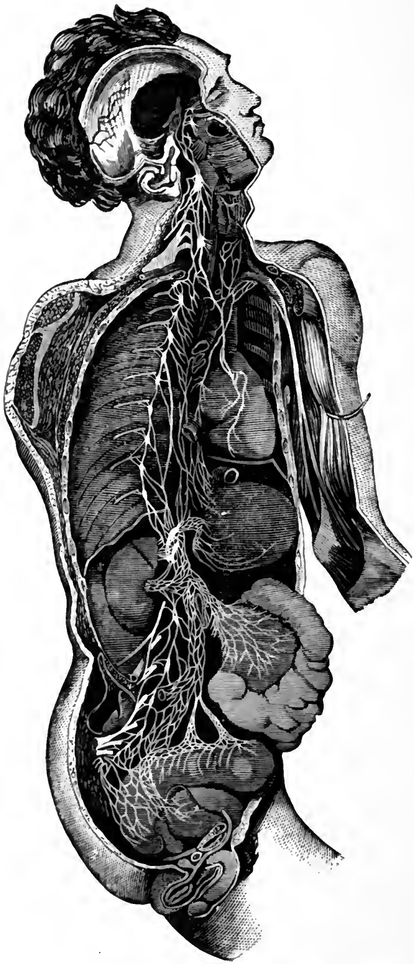
Sympathetic System.

Primarily, the **sympathetic system** (Fig. 87) consists of a double chain of ganglia and communicating nerves which lie on either side of the vertebral column and extend throughout its entire length. Other ganglia occur in connection with some of the cranial nerves, more especially the vagus and trigeminus. There are ganglia and plexuses connected with the various organs (*e. g.*, cardiac and solar), and still others in the substance of some of the organs (*e. g.*, stomach and intestines); still others in connection with the bloodvessels. The sympathetic system has numerous communications with the cerebro-spinal system.

The *fibres* of the sympathetic nerves are often smaller than those of the cerebro-spinal system, and among them are a large number of non-medullated fibres. The sympathetic nerves do not differ materially from the cerebro-spinal. They are very similar. The occurrence of ganglia upon the sensory branches of the spinal nerves and upon the sensory cranial nerves (pneumogastric, glosso-pharyngeal, and trigeminus) adds to the similarity. Then, too, the frequent communications between the two systems practically make one system of them, and the division is largely one for convenience.

Communication of cerebro-spinal and sympathetic systems: From each spinal nerve is given off a communicating branch to a neighboring sympathetic ganglion. These branches contain both motor and sensory fibres. Thus it is seen that all

Fig. 87.



Ganglia and nerves of the sympathetic system.

impulses travelling along the sympathetic system may either start or terminate in the cerebro-spinal.

By the term **ganglion** is meant a collection of gray and white nerve-substance, which is usually oval in outline, and is frequently found in the course of a nerve-trunk. In the sympathetic system the ganglia contain numerous nerve-cells, smaller than those of the brain and spinal cord, and from these cells arise nerve-fibres which distribute themselves in the plexuses.

Ganglia of the sympathetic. The long chain of ganglia, with the various plexuses, of the sympathetic system are classified regionally as cephalic, cervical, thoracic, abdominal, and pelvic ganglia and plexuses.

Cephalic ganglia: In the *head* the sympathetic ganglia are four in number—ophthalmic, spheno-palatine, submaxillary, and otic ganglia. Each has communications from the general sympathetic; and from the cranial nerves both motor and sensory fibres.

Ophthalmic ganglion: It is a small ganglion situated in the orbit, and receives communications from the sympathetic and from the motor oculi (third) nerve, a motor branch, and from the trigeminus (fifth) nerve a sensory branch. Its branches pass into the eyeball (ciliary nerves), and are distributed in the iris. Their function is the control of the pupil, of the apparatus of accommodation, and of the vaso-motor function in the vessels of the eye.

Spheno-palatine ganglion: It is situated in the spheno-maxillary fossa, and receives branches from the cervical sympathetic system and motor fibres from the facial (seventh) nerve, and sensory from the fifth. Its branches are distributed to the mucous membrane and muscles of the palate and uvula, and to the naso-pharynx. They are both sensory and motor.

The *submaxillary ganglion lies* in close proximity to the submaxillary gland. It receives branches from the superior cervical ganglion by way of the plexus on the facial artery, and a sensory branch from the lingual branch of the fifth nerve. Its motor branch is through the chorda tympani nerve from the seventh or facial nerve. Its branches are distributed to the submaxillary gland and control its function.

The *otic ganglion* is a small ganglion lying upon the third

division of the fifth nerve as it emerges from the foramen ovale. It has branches from the sympathetic on the middle meningeal artery, and both a motor and a sensory communication from the fifth, as well as a branch from the glosso-pharyngeal through Jacobson's nerve. Its branches are motor, to the tensor palati and tensor tympani muscles; and sensory, to the mucous membrane of the tympanum and Eustachian tube.

Cervical ganglia: There are two—a superior and an inferior (with sometimes a third, middle)—ganglia on each side (Fig. 87). These ganglia receive communications from each of the cervical spinal nerves and from each other. Their branches are given off: (1) to form the *carotid plexus*, which follows the carotid artery and its branches, forming by its inosculations the vaso-motor plexuses of the carotid system. (2) To furnish branches for distribution to the thyroid gland, larynx, trachea, pharynx, and œsophagus. (3) To form the *cardiac nerves*, which are distributed in the cardiac plexus.

Thoracic ganglia: In the chest the ganglia are numerous (Fig. 87), and each ganglion receives two branches of communication from the intercostal nerve above it, while the relationship of the ganglia is maintained by the intercommunicating chain. The nerves originating here are distributed to the plexuses on the thoracic aorta, and to those of the lungs and œsophagus.

Abdominal ganglia: In the abdomen there is an aggregation of ganglionic enlargements situated upon the cœliac artery, known as the *semilunar* or *cœliac ganglion*. It communicates with the thoracic ganglia and with all the lumbar nerves. From this centre proceed a multitude of diverging and inosculating fibres, which, from their common origin and radiating course, are called the *solar plexus*. Its secondary plexuses, accompanying the branches of the abdominal aorta, are distributed to the stomach, intestines, spleen, pancreas, liver, kidney, and internal organs of generation.

Pelvic plexuses: The plexuses of the pelvis are derived from four or five pairs of ganglia situated on the anterior portion of the sacrum and terminating in the *ganglion impar*, lying upon the coccyx. Its fibres join those from the solar

plexus, and are distributed with them along the course of the branches of the internal iliac arteries.

Sympathetic system—function: The action of the sympathetic is principally shown in the *organs of nutrition* and *secretion* and in the *vascular system.* The sympathetic also plays an important part in the *special senses—e. g.*, dilatation of the pupil is effected through it, and probably accommodation is acted upon by fibres, other than the oculomotorius, which come through the lenticular ganglion. The tensor tympani muscle is supplied, indirectly, from the otic ganglion. The efferent nerve-fibres of the sympathetic system send to the muscles of the vascular system vaso-motor (*i. e.*, vaso-constrictor and cardiac accelerator) and also vaso-inhibitory fibres (*i. e.*, vaso-dilator and cardiac inhibitory). To the muscles of the viscera they send both vaso-motor and vaso-inhibitory fibres.

Sensory and motor influence of the sympathetic: It will be remembered that the spinal nerves, both afferent and efferent, act very quickly upon the tissues supplied by them; the sympathetic nerves act more slowly. Thus, if the afferent nerve of a ganglion or its efferent nerve be stimulated, there is a slow wave-like series of motions set up in the parts supplied, which continue for some time after the stimulus is withdrawn. This is particularly well seen in *intestinal peristalsis*, which may be excited by stimulation of the intestine or of the semilunar ganglion or of the branches of the solar plexus.

Relation of the sympathetic to the secreting glands: There has been demonstrated in some of the secreting glands—and it is probably true for all—that functional stimuli, distinct from the vaso-motor, come through the sympathetic nerves, and that these fibres are closely associated with the vaso-motor fibres. Thus, in the stomach the secretion of the gastric juice is only temporarily suspended by the section of the vagi, and is resumed by the action of the sympathetic, showing that the control is by the sympathetic. Thus it is seen that there are true "secretory" nerve-fibres.

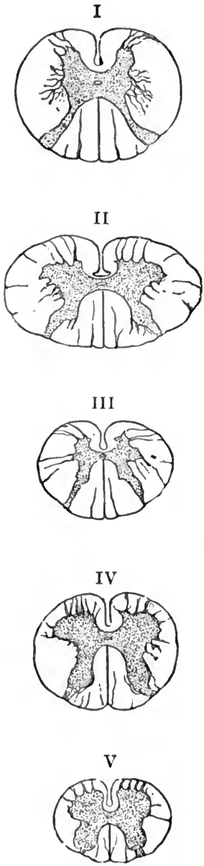
Vaso-motor fibres: The vaso-motor function of the sympathetic has been discussed under the section on Circulation.

Spinal Cord.

Gross anatomy: The spinal cord is that portion of the cerebro-spinal nervous system contained within the spinal canal. It connects with the medulla oblongata, and terminates in a fine thread of gray matter (the filum terminale) at about the second lumbar vertebra. In form it is irregularly cylindrical, and varies in the size and shape of its cross-section at various levels, as is shown in Fig. 88. It is incompletely divided into symmetrical halves, and its mid-line is indicated in front by a fissure (anterior median fissure) which extends for about one-third its antero-posterior diameter; behind by a deeper but narrower fissure (posterior median fissure), which involves about one-half of the same diameter. It is composed of white and gray substance.

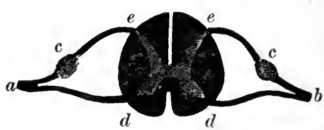
Issuing from the cord along its course are thirty-one pairs of *nerves*. Each of these spinal nerves is made up of an anterior and a posterior root (Fig. 89), of which the latter is the larger. The anterior root arises between the anterior and lateral white columns, the posterior be-

FIG. 88.



Transverse sections of the spinal cord in man. I, upper cervical region: II, lower cervical region; III, dorsal region; IV, lumbar enlargement; V, lower extremity.

FIG. 89.



Transverse section of the spinal cord. *a*, *b*, spinal nerves of the right and left sides; *d*, origin of the anterior root; *e*, origin of the posterior root; *c*, ganglion of the posterior root.

tween the posterior and lateral columns. On each posterior nerve-root is found a ganglion immediately beyond its point of emergence. The function of this seems to be trophic.

The *white substance* is arranged externally to the gray in each half of the cord, and is so disposed as to be conveniently divided for purposes of description into three columns, known respectively as the anterior, lateral, and posterior columns of the cord. There is also a thin band of white substance at the base of the anterior median fissure (the white commissure). The gray matter fills in the central portion of the cord, and is variable in its amount, the calibre of the cord at its enlargements being increased by the increase in the amount of gray matter at these points (Fig. 88). The white substance will be noticed to diminish quite regularly in the sections of the cord from above downward, as seen in this series. The gray substance is not completely halved by the anterior and posterior fissures of the cord, but is continuous across the mid-line (gray commissure); and in it at the centre is a minute canal communicating with the ventricles of the brain. The gray matter is more abundant between the lateral and anterior and between the lateral and posterior columns of the white substance; the names anterior and posterior horns (cornua) are given to these regions respectively.

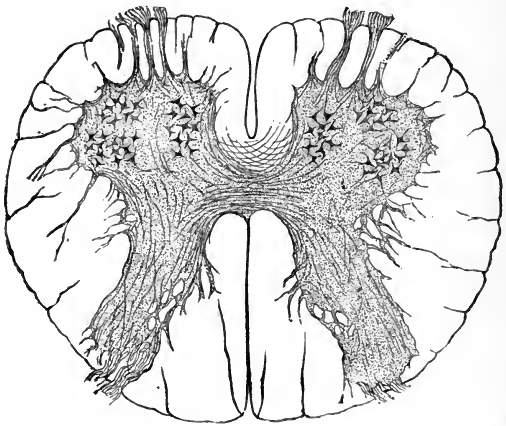
Spinal cord—microscopic examination: Under minute examination the *white matter* is found to be made up of medullated nerve-fibres, which collect to form the anterior and posterior nerve-roots, and communicate with other regions of the cord.

The *gray matter* contains multipolar cells of varying size and shape, with axis-cylinders and "branching" processes lying in the neuroglia ("connective tissue"). The multipolar cells are some of them quite large. In the anterior horn of the gray substance the axis-cylinder-processes of the nerve-cells connect directly with fibres forming the anterior nerve-roots (Fig. 90); but in the posterior cornu the communication is indirect—*i. e.*, through the branching processes and the divided axis-cylinders of the *collaterals* of the pos-

terior nerve-roots, forming thus by contiguity what are known as *end-arborizations.*

Origin and course of nerve-roots: (*a*) *Anterior nerve-roots* are derived from (1) the anterior columns of the cord, but some fibres come through the commissure from (2) the opposite side, and some come from (3) the lateral tract. Still other fibres arise from (4) the multipolar cells in the anterior cornu of the gray matter. The fibres of the anterior nerve-

FIG. 90.



Transverse section of the spinal cord in man (lumbar region).

roots are efferent—*i. e.*, they carry impulses from the centre (brain) to the periphery.

(*b*) *Posterior nerve-roots* give off *collaterals* which enter the posterior horn of the gray matter, and the ultimate fibres break up and form "indirect" communication with the branching processes of the large multipolar cells, but some fibres cross through the gray commissure to the opposite side. The fibres of the posterior roots are afferent—*i. e.*, they carry impulses from the periphery to the centre in the cord, medulla, or brain.

The *course* of all the fibres through the cord itself has not been determined with absolute accuracy. Certain fibres, how-

ever, have been traced through their length, notably the fibres of the *pyramidal tracts*, in the anterior and lateral columns.

It has been calculated that only about one-half as many fibres enter the spinal cord from the brain as leave it through the nerves; therefore it must follow that some fibres originate from the cord. The increase in gray matter in the cervical and lumbar enlargements, where the fibres for the large plexuses of the nerves (branchial and lumbar) are given off, confirms this view.

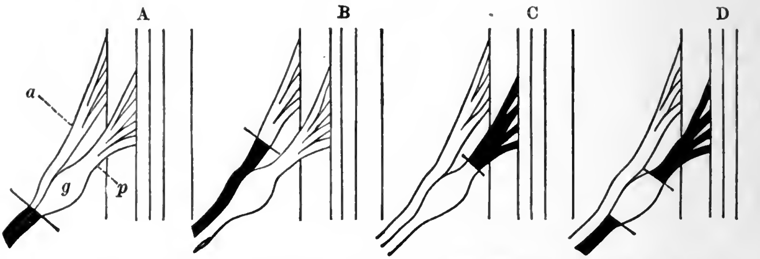
Spinal cord—recurrent sensibility fibres: Certain afferent fibres in the nerve-trunks of the body do not pass *directly* into the posterior nerve-roots and so to the spinal cord, but take an erratic course as follows: After leaving the nerve-trunk these fibres, known as the recurrent sensibility fibres, pass into the *anterior nerve-root*, being mingled with the efferent fibres for a short distance; then these fibres double on their course, return to the point of junction between the anterior and posterior nerve-roots, to follow by way of the posterior root the normal course to the cord. These fibres form but a small proportion of the afferent fibres, and the purpose of their erratic course is not easily explainable.

Trophic centres of nerve-roots—degeneration: The posterior nerve-roots seem to be dependent upon the ganglia which are found upon them for trophic influence. The anterior root in a similar way seems to depend upon a trophic centre in the gray matter in the anterior horn.

Division of a nerve is followed by a degeneration or breaking down of the axis-cylinders of its fibres within a day or two, the loss of function being an earlier and immediate manifestation. This degeneration is centrifugal—that is, does not proceed toward the spine, but to the periphery. If the posterior root be cut, however, between its ganglion and its emergence from the cord, the degeneration is toward the cord —*i. e.*, centripetal—and the nerve beyond the ganglion does not degenerate. The anterior root cannot, however, be divided at any point beyond its emergence without centrifugal degeneration of the fibres (Fig. 91). The regeneration takes place slowly if the continuity of the nerve is at once restored, and may even follow after the nerve has degenerated for some

months and a complete loss of function has affected the part supplied by it. The fact that the axis-cylinders are restored only in this way is of interest, as showing the influence of the trophic centres on the nerve-growth.

FIG. 91.



Degeneration of spinal nerves and nerve-roots after section. A, section of nerve-trunk beyond the ganglion; B, section of anterior root; C, section of posterior root; D, excision of ganglion; *a*, anterior root; *p*, posterior root; *g*, ganglion.

The **functions** of the spinal cord may be tabulated as follows:

(*a*) *Conduction*, or carrying impulses between centre and periphery;

(*b*) *Transference—i. e.*, an apparent transferring of impression from one set of fibres to another;

(*c*) *Reflex action—i. e.*, the origination of action in response to stimuli from the periphery;

(*d*) *Augmentation*, or a resulting effect in excess of the exciting cause;

(*e*) *Automatic acts*, from corresponding centres;

(*f*) *Coördination*, or the adjustment of the workings of different parts of the body to one another;

(*g*) *Inhibition of reflex acts.*

Conduction: Than by the spinal cord there is practically no other nervous communication between the brain and the musculo-cutaneous system; hence through it must come all the nerve-impulses which pass to or from the brain. In other words, every sensory impulse that is *felt* and every motion that is *willed*, perception and volition being attributes

of the brain, must be conducted through the nerve-fibres of the spinal cord to the brain, and *vice versâ*.

The student must not suppose that in all instances a continuous nerve-fibre runs from the central cell in the brain to the peripheral end-organ, and *vice versâ*. The nerve-fibre is often broken at one or more places along its course, the end of the fibre terminating in a brush-like ending which "articulates" with the dendrites of a secondary or relay cell. The impulse is thus communicated to the second cell, which in turn transmits the impulse along its own nerve-fibre and so on.

The conducting fibres in the cord lie chiefly in the white matter; whereas the gray substance represents the cell-elements as well.

The conducting fibres have definite positions in the cord, and each portion has fibres which always conduct the same *kind* of impressions.

Most of the *motor fibres* cross to the opposite side in the medulla oblongata (decussation of the pyramids), and the impulses pass down by the lateral columns in the crossed or lateral pyramidal tract on the side opposite to that in which they originate. There is also a set of motor fibres which does not cross, but passes directly to the same side in the anterior columns, and decussates in the anterior or white commissure near the point of distribution. The destination of these fibres is variable, for the reason that the amount of decussation in the medulla is not constant; but, as a rule, the fibres in the direct tract go to the upper portion of the body. The cells in the anterior cornu of the gray matter of the cord originate many of the fibres which go to the nerves. This is demonstrated after division of the cord by stimulating these fibres: a series of coördinated motions follows, and this stimulus may be applied direct to the fibres or through the sensory nerves.

The course of the *sensory fibres* (Fig. 92) is somewhat problematical, but certainly these impulses enter the cord by the posterior nerve-roots. The fibres conducting them break up as described, and cross to the opposite side of the cord through the gray commissure. It is probable that after decussating the fibres communicate with multipolar cells, and thus

pass on as white fibres in the lateral columns. These fibres after entering the lateral columns (of the opposite side) pass to the medulla as a distinct tract—the antero-lateral ascending

Fig. 92.

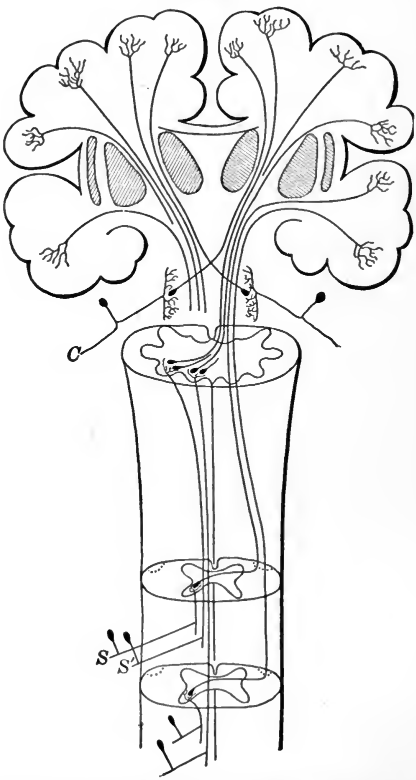


Diagram showing pathway of the sensory impulses. On the left side *S S'* represent afferent spinal nerve-fibres; *C*, an afferent cranial nerve-fibre. These fibres terminate near central cells, the neurons of which cross the middle line and end in the opposite hemisphere (Van Gehuchten).

tract—at the periphery of the lateral, extending into the anterior column.

It is by this tract that sensations of *pain* and of *temperature* are supposed to pass. There are also afferent fibres in the posterior columns—the posterior median—by which the sensations of *touch* and *weight* (or muscular sensation) are believed to pass; the latter, however, does not decussate. To recapitulate: sensations of pain and temperature are transmitted through the lateral columns, and those of touch and weight through the posterior columns.

Transference: Impressions conveyed by a centripetal nerve-fibre, it has been stated, pass uninterruptedly throughout its whole length without being communicated to adjacent fibres. When such an impression reaches a nerve-centre in the cord, it may seem to pass to another fibre or set of fibres, so that the pain or other sensation is *felt* in an entirely different part from that in which the stimulus started. At the same time the *primary* impression may also be conducted to the brain, so that the sensation seems to come from two different places. This phenomenon, known as transference, cannot be well explained, yet instances of it are very frequent. In disease of the hip the pain is frequently *felt* in the knee alone, yet the latter may be perfectly sound. A biliary calculus will often cause pain in the glans penis.

Reflex action: Certain sensory stimuli are received, pass up the nerve-trunks to the posterior nerve-roots, and thus to the spinal cord. In the cord the impulse may be sent to the brain, producing the consciousness of pain, etc.; or else the impulse in the cord may be transmitted directly to some motor cell in the anterior horn, stirring it to activity, with the result that there is some muscular action. For example, a person may be tickled with a feather: the subject brushes away the offending object either with or without consciousness of what he is doing. If he does it unconsciously, the reflex act takes place in the cord; if he brushes away the feather as a result of the impression received in his brain, the reflex act took place in the brain. Furthermore, a person may perform a reflex act through the reflex centres in the cord, and yet after the act is completed he may receive the sensory impulse in the brain. From this we may deduce the following rule:

A reflex act taking place through the cord, may or may not be accompanied by conscious sensation; but if it is accompanied by conscious sensation, the consciousness is always later in point of time than the act. Thus we may say a reflex action is an action which results from a centripetal nerve-impulse passing to a nerve-centre in a ganglion, and there transforming to a centrifugal impulse passing to a muscle. Such an action may be simple and involve a single muscle, or complex and involve many: thus, a ray of light falling upon the retina causes a simple reflex contraction of a single muscle, and the iris contracts. As an illustration of a complex reflex action, however, irritation of the larynx causes not only a closing of the glottis, but a contraction of all the muscles involved in forced expiration or coughing.

Reflex acts are more noticeable in the cerebro-spinal system; but they may belong to either, or may be mixed, the impulse going by the one system and returning by the other. Examples: sneezing, coughing, swallowing are cerebro-spinal reflexes; the vaso-motor reflexes are largely sympathetic, but the centripetal nerve is often cerebro-spinal, as in the secretion of saliva or in blushing.

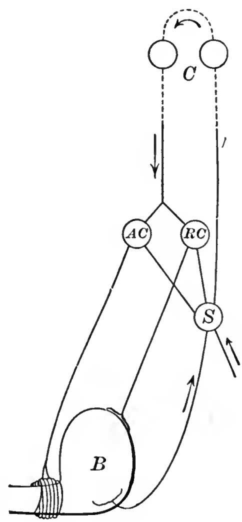
The *spinal cord* in man is so much under the control of the higher centres that its capabilities for reflex action are often overlooked. After injury to the spinal cord the reflex acts are apt to be purposeless and fruitless. In many lower animals reflex actions, after the cord has been divided, are often followed by extensive and coördinated movements. In the frog this is especially marked. Yet the difference is one of degree only. In man many minor acts are performed as reflex movements occurring through the aid of the spinal cord, although the cord is incapable of initiating them of itself.

Special reflexes of the cord: Under this heading we may enumerate the micturition, defecation, and genital centres:

(1) *Micturition:* Here the sphincter of the bladder is kept in a normal state of contraction, until such time as afferent impulses are sent to the cord from the neck of the bladder owing to pressure of urine; an efferent impulse is then aroused which releases the sphincter and at the same time

causes the wall of the bladder to contract (Fig. 93). Although this act is a reflex one, it is under the control of the will to a large extent.

Fig. 93.



Schema of micturition. *AC*, *RC*, *C*, automatic, reflex, and cerebral centres; *B*, bladder; *S*, sensory centre acted on by afferent impulses (Landois).

(2) *Defecation:* The nature of the act is identical with that of micturition: the impulse arising from the presence of flatus or fæces, with the resultant relaxation of the sphincter ani and contraction of the lower bowel.

(3) *Genital:* Controls the erection of the penis and the ejaculation of semen. Under this heading we may also include the centre for *parturition.* Stimulation of the interior of the uterus by its contents may excite the centre enough to cause it to send out impulses producing uterine contractions and expulsion of its contents. That delivery can take place in a person under the influence of chloroform shows that the centre is independent of the will. As in the case of micturition or defecation, there is an accessory action of the abdominal muscles, for the most part reflex and involuntary.

All these reflexes have their seat in the lumbar enlargement of the cord.

Varieties of reflex acts: Reflex actions may be *simple* or *coördinated*, *primary* or *secondary.* In the simplest reflex act only a single nerve-cell with an afferent and an efferent fibre is concerned. In most reflexes, however, it is probable that several cells are involved and act in concert. Primary reflex acts are those such as sucking, which the infant can perform as well as the adult. Secondary or acquired reflexes are those which require an effort of the will for their first performance, but which become habitual after frequent repetition. They are described under *Coördination.*

Augmentation: The resultant reflex act of a stimulation may be far in excess of the amount of stimulation received. For example: a tiny drop of acetic acid applied to the skin of a decapitated frog may result in most frantic efforts on the part of the animal to rub off the offending fluid, although the irritation can be but slight. The explanation lies in the fact that the sensory nerve-fibres, as they enter the cord, individually break up into an ascending and a descending limb. These two limbs in turn give out, at several points along their course, collaterals, which break up into sets of brush-endings. These "brush-endings" connect with the dendrites of motor cells. Thus it is seen that *one* sensory fibre may stir into activity *several* motor fibres, so that the resultant act is *augmented*.

Automatic acts: In normal subjects the cord is not the seat of many automatic acts. But if the brain be destroyed or severed from the cord, certain centres which normally are secondary assume primary importance and are capable of automatic activity. The best examples are the vaso-motor centres of the cord.

Under the capitulation of *normal automatic centres* we may include those governing the sweat and general muscular tone.

The student must bear in mind that there are many automatic acts whose centres are outside of the cord, their origin being in *local* centres. Thus, there are certain actions which continue, and, while they are closely related to reflex action, do not seem to be true reflexes, but to originate in the part. Thus, the peristaltic action of the alimentary tract is not dependent upon the presence of food in the intestines, but may be excited in the absence of food or checked when it is present. This action has been referred to small ganglia and nerve-plexuses found there (Auerbach's and Meissner's), and is considered to originate in the local nerve-centres. This is what is known as automatism or automatic nerve-action.

Coördination: The coördination of the cord is nothing but a repetition of ordinary reflex acts for our daily lives. For example, we look upon walking as a coördinate movement. It is performed unconsciously and depends on reflex activity

resulting from cutaneous and muscular sensations, or the sense of position in space.

Inhibition of reflex acts: This function does not *originate* in the cord, but in the brain; but the transference of the impulse takes place in the reflex centres of the cord. It is the ability to control or modify reflex action by an effort of the will or by mental action which is not consciously voluntary. As an example of this, if the palm of a sleeping child be touched by the finger, the baby's hand will grasp the finger; but if the child is awake, no such reflex occurs: it is checked by mental action. Again: one may avoid crying out when in pain by an effort of the will, or may hold the feet still when the soles are tickled. An example of this inhibition of reflex action is offered in the knee-jerk, an important sympton in the diagnosis of certain nervous diseases. When the patellar tendon is tapped sharply with the tips of the fingers the foot and leg are suddenly jerked forward. If the patient is ignorant of what is to be done, the amount of motion obtained is diagnostic; but if he knows what is expected, the result is apt to be deceptive, as this reflex can be entirely prevented by the will. For this reason, if the patient knows the symptom, it is always tried when he is off his guard.

The object of reflex acts is to save time, suffering, and wear and tear on the body; but if we had no check on reflex activities, we should spend all our time making efforts to escape outside stimuli.

Medulla Oblongata.

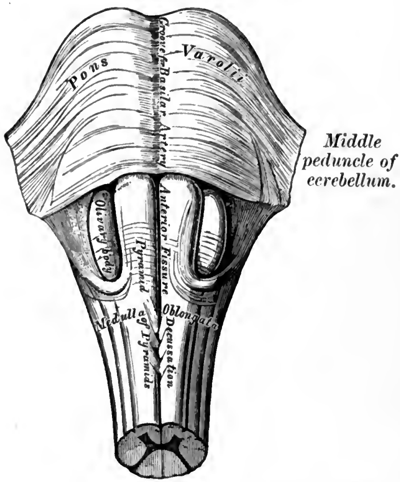
Gross anatomy: The *medulla oblongata*, or bulb, is a column of white and gray nerve-substance, the lowermost portion of the brain, and connecting with the spinal cord below.

The *white substance* is composed of the medullary fibres continued up from the cord, and the *gray matter* is arranged variously between the bands of white fibres. It has an anterior and a posterior fissure, corresponding to those of the cord, and the central canal of the cord here opens into the fourth ventricle.

The medulla continues in a general way the arrangement

of the fibres in tracts of the cord below; but as the diameter is greater, the general shape is pyriform and the shape of the columns is changed (Fig. 94). The anterior columns of the cord correspond in position to the pyramids of the medulla; the posterior columns, to the restiform bodies; and the lateral columns correspond to the lateral tract of the medulla with the olivary bodies. The *fibres*, however, do not follow this

FIG. 94.



Medulla oblongata and pons Varolii, anterior surface.

arrangement so closely, but are distributed variously in the medulla.

The **anterior columns** of the cord send some of their fibres (the direct *pyramidal tract*) into the pyramids, forming continuous tracts. Fibres from the lateral columns also enter the pyramids, but cross in bundles *to the opposite side.* These fibres may be seen crossing the anterior fissure between the pyramids by gently separating them. This is known as the *decussation of the pyramids.* The fibres which cross in this way belong in the cord to the portion of the lateral column known as the *crossed* or *lateral pyramidal tract.*

Further course of the fibres of the pyramids: Almost all of the fibres pass on through the pons Varolii and crusta of the mid-brain, to be distributed to the cortex of the hemispheres by way of the internal capsule and corona radiata. A few of the fibres (external arciform) pass to the cerebellum by way of the restiform body.

Lateral columns: The lateral column of the cord is broken into three tracts in the medulla: one, we have just seen, joins the anterior pyramid of the opposite side by the decussation; a second joins the restiform body on its way to distribution in the cerebellum; while the third set of fibres passes through the deeper part of the medulla (formatio reticularis) and tegmentum of the mid-brain, and reaches the ganglia at the base of the brain; some of these go to the fillet.

Posterior columns: The fibres of the posterior column continue on as the funiculi cuneatus and gracilis of the medulla. These in turn terminate in their own nuclei, from which new fibres arise and pass to the fillet of the opposite side. The restiform body, just above the ends of these funiculi, for the most part reaches the cerebellum.[1]

Olivary bodies: Each is a mass of white nerve-substance containing a central gray nucleus. There are communications between it and some of the tracts from the cord, especially from those tracts of the anterior and lateral columns which go to the ganglia at the base of the brain.

Medulla—arrangement of the gray matter: As the fibres which form the crossed pyramidal tract pass from the lateral column to decussate into the pyramid of the opposite side, they push the anterior cornu of the gray matter backward; and this is still further accomplished by the olivary body, until the gray matter is spread out toward the posterior surface of the medulla at its upper part. Here the central canal of the cord has widened out to form the lower part of the

[1] In speaking of these fibres it has been convenient to say that they "pass" in certain directions or "are distributed" in some situation. It must not be forgotten that they are afferent and efferent medullated nerve-fibres, and that such terms must be considered as somewhat figurative. In reality, it would not seem proper to speak of an efferent fibre as being "distributed" at its origin, but convenience and usage permit the use of these and similar expressions.

fourth ventricle, and the gray substance is aggregated just under the floor of the ventricle. There are also some other collections of gray matter—for example, in the olivary bodies.

In this gray substance are the nuclei of origin of some of the cranial nerves: the spinal accessory, hypoglossal, pneumogastric, and glosso-pharyngeal nerves; and roots of the auditory, of the facial, and of the trigeminus nerves, arise in this important collection of gray matter. Of the smaller collections of gray substance, probably none has the peculiar interest which the floor of the fourth ventricle possesses for this reason.

Function of the medulla: The functions of the medulla are practically of the same kind as those possessed by the spinal cord, but of a higher degree. They are as follows: (*a*) conduction; (*b*) reflex action; (*c*) automatic action; (*d*) inhibition.

Conduction: As the medulla is the sole connecting link between the upper parts of the brain and the cord, it necessarily contains all fibres passing between these limits. Thus it conducts all impulses and transmits all sensations.

Reflex action: The medulla resembles the spinal cord in being the seat of reflex acts; the only difference between them being in the fact that many of the reflexes performed by the former are of much greater importance to life than any performed by the latter. Of the many reflex acts arising from the medulla, the following are examples:

(1) That part of *digestion* which is performed in the mouth is dependent upon medullary reflexes—mastication, deglutition, and the *secretion of saliva*; and, probably, the secretion of the pancreatic and other digestive juices. In this connection the so-called *vomiting-centre* may be noted.

(2) The *respiratory* functions are so-called automatic functions of the medulla, and are capable of being sustained by the nerve-force derived from the medulla alone. The centres for *coughing* and *sneezing* are also here. The pneumogastric and phrenic nerves convey the afferent and efferent stimuli, though there may be communications with other nerves whereby sensory stimuli are applied.

(3) "*Cardiac depressor*" is the name given to a bundle of nerve-fibres running from the heart to the medulla, which is

stimulated when the heart is overworking against a high tension in the bloodvessels. The result of the stimulation of this "cardiac depressor" is a stimulus to the vaso-motor nerves which results in a dilatation of the arterioles, and consequently the tension is diminished and the overwork of the heart ceases. This reflex act takes place in the medulla.

Automatic action: The impulses which are sent out to muscles without apparent afferent stimuli, and without an effort of the will, are called *automatic*. Such rhythmic impulses as those which maintain the respiratory function belong to this class. It is not to be doubted that such actions are reflex, and in response to stimuli. In the case of the lungs, for example, the presence of deoxygenated blood may serve to excite an afferent impulse. Nevertheless, some authors distinguish between automatism and reflex action. This automatic action cannot be considered as at all the same as an action of the brain proper, like volition, but rather as a high grade of reflex action. On the other hand, some authorities claim that it is *truly automatic* in some of its acts, in that it is capable of direct stimulation by the condition of the blood circulating through the environment. It is bilateral, and probably consists of both an inspiratory and an expiratory part. It may be influenced to a certain extent by voluntary impulses.

Inhibition: This is the control or inhibition of action through the nerves which are distributed from this region and through the communications with other centres in the cord. Besides, there are supposed to lie in the medulla centres which maintain the *nutrition* and *tone* of the muscles. These are known as *control* and *tonic* centres.

Special centres: In addition to the centres already given there is a considerable number of centres in the medulla which control many important and complicated coördinated muscular actions. These are centres of reflex action for the most part—that is, are called upon to act in response to stimuli derived from an afferent impulse or to a voluntary effort.

The following are examples:

(1) Regulation of the *heart's action* is found here, both *inhibitory* and *accelerator* centres communicating through the vagus.

(2) *Vaso-motor*—regulation of the unstriped muscular fibre of the arteries is also accomplished by the medulla. A peculiar vaso-motor disturbance is brought about by injury of one centre of the medulla—namely, the interference with the glycogen-function of the liver and the appearance of sugar in the urine—the *diabetic* centre.

(3) Various centres which have to do with the regulation of the *body-temperature*. The vaso-motor centres we have already mentioned. There are also found special *sweat*-centres; and, furthermore, a control of the special sweat-centres found in the cord is here maintained. Upon plausible theoretical grounds there is also assumed to be a *heat-inhibitory centre*, by which the heat-production is controlled without reference to vaso-motor conditions.

(4) Also see example under "Reflex action."

Other functions: The origin of the roots of certain of the cranial nerves here has caused the special senses of *hearing* and of *taste* to be referred to this region; and the connection with the sympathetic system through the cord has caused the centre for the *dilatation of the pupil* to be located in the medulla. *Phonation* is also dependent upon the action of nerves arising in this focus of gray matter, and no voluntary or reflex sound can be produced by an animal in which the speech-centre in the medulla is destroyed. The origin here of the hypoglossal and pneumogastric nerves, involving as they do the movements of the tongue and glottis, controls both the acts of phonation and articulation.

Demonstration of respiratory functions of the medulla: For this purpose we select an active, healthy frog: If the spinal cord be removed up to the medulla, the respirations continue, and in the same way they do not cease if the hemispheres be removed without disturbing this organ; or, if both cord and hemispheres be removed without disturbing the medulla, the movements of breathing will continue. If the medulla is injured at the origin of the pneumogastric nerve, however, the movements of respiration cease and the animal dies. The same occurs when a similar injury happens in the higher animals and in man. Death occurs instantaneously in this way when the medulla is broken near the axis in executions

by hanging—"the neck is broken"—or when an animal is killed by "pithing" in laboratory experiments.

Glosso-labio-laryngeal paralysis: It may be of interest at this point to observe the pathological changes that occur in the medulla in producing the disease known as glosso-labio-laryngeal or bulbar paralysis: It is a progressive degeneration of the gray matter of the medulla, and it shows itself first in a paralysis of the tongue, which renders articulation of certain sounds indistinct: as the degeneration progresses in the medulla articulation becomes more and more impossible and deglutition is affected. The disease continues to affect more and more of the functions dependent upon the medulla, until death ensues as a result of involvement of the cardiac and respiratory centres or of inability to take food.

Pons, Crura Cerebri, and Corpora Quadrigemina.

The **pons Varolii** is a collection of nervous tissue lying immediately above the medulla. It consists of white fibres, with areas of gray matter filling in the intervals between the fasciculi of white fibres. The white fibres connect the mid-brain with the medulla, and also pass between the hemispheres of the cerebellum. What is the function of the gray matter is little known; but some of it is directly continuous with that of the medulla, and, like it, active as a centre of nervous force. In the pons is the decussation of many nerve-fibres, among which are some of the fibres of the facial nerve arising in the floor of the fourth ventricle.

Paralysis following lesions of the pons: The so-called *crossed paralysis* may follow lesions in the lower portion of the pons —that is, paralysis of sensation and motion, more or less complete, of the opposite side of the body, with paralysis of the facial muscles of the same side as the lesion.

Crura cerebri: The crura are formed of fibres passing from the medulla through the pons Varolii, to the hemispheres of the cerebrum. They divide so as to form two sets of fibres: the more superficial (crustæ) are mostly motor or efferent fibres which are continuous with the pyramidal tracts in the cord; while the deeper (tegmentum) layer of fibres are afferent or

sensory, and are derived largely from the lateral and posterior tracts of the cord. Lying between these bands of fibres is a mass of gray substance (locus niger) whose function as a nerve-centre is not understood, though it has to do with coördination of the muscles, and especially with regulation of the muscles controlled by the motor oculi nerve.

Paralysis following lesions in the crura: This is paralysis of the opposite side of the body, both of sensation and motion, and of a degree of intensity depending upon the size of the lesion; and, besides this, paralysis of the motor oculi nerve of the same side as the lesion. There is a derangement of the coördination of motions which follows lesions of this region beyond that which belongs to the motor paralysis; this is often shown in rotary movements when the subject attempts to walk. It is inferred that there are coördinating influences derived from the crura.

The **corpora quadrigemina** are four rounded eminences placed in pairs, two anterior, two posterior. They are situated on the dorsal aspect of the mid-brain below the posterior lobes of the cerebral hemispheres and between the optic thalami and third ventricle in front and the cerebellum behind.

Functions: The anterior corpora quadrigemina are the homologues of the optic lobes in some of the lower animals, and the anterior pair may be regarded as important centres for the visual and motor functions of the eyes. The posterior pair are more intimately associated with the sense of hearing. The special functions of the corpora quadrigemina will be more fully discussed under the special senses. Not only does blindness follow lesions of the anterior corpora quadrigemina, but there is often atrophy of them when the eyes are destroyed.

Cerebrum.

The **cerebrum** is composed of two *hemispheres*, connected by a commissure of white fibres, the *corpus callosum*, and of the third ventricle and optic thalami (di- or thalamencephalon).

The two *hemispheres* are separated by a deep fissure extending from before backward, and in the interior of each is

found a cavity known as the *lateral ventricle.* The hemispheres are connected directly with the spinal system by the crura cerebri and medulla, and with each other by the corpus callosum. They are composed of white and gray nerve-substance, and the latter is arranged largely at the periphery of the hemispheres; the former being made up of communicating nerve-fibres which connect the various portions of the hemispheres with each other, and the hemispheres with other parts of the cerebro-spinal system, thus allowing a free control of the impulses arising from one cell or set of cells by other cells in the gray matter.

The **surface of the cerebrum** is divided into regions by *fissures,* which separate one part from another. These fissures are always present, and upon them depends the determination of the division of the cerebrum into *lobes.* Fissures which are of use in locating the lobes of cerebral matter are the fissure of Rolando, the fissure of Sylvius, and the parieto-occipital fissure (Fig. 95).

Convolutions: The surface of the brain is further cut up by a number of other clefts, known as *sulci;* and these separate the surface into a number of distinct masses or convolutions. The depth of the sulci and their number determine the quality of the brain in respect to its degree of development; thus, the convolutions in man are much deeper and more numerous than in the lower animals. The sulci are not invariable in position or number in different brains.

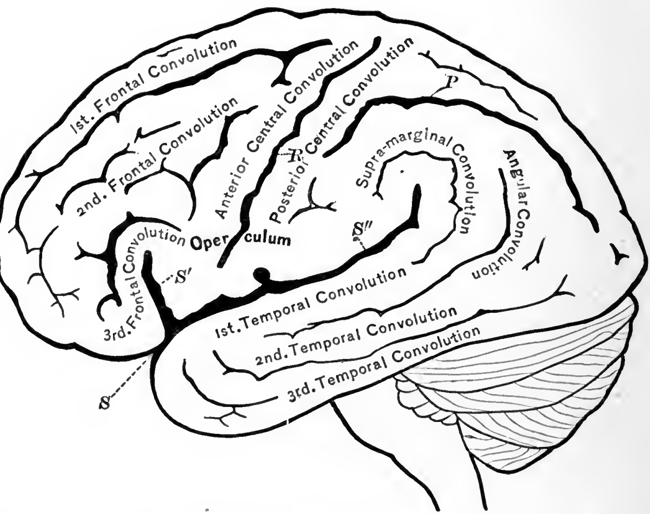
Regions of the cerebrum: (1) *Frontal lobe:* This lobe is bounded by the fissure of Rolando, and contains several convolutions which include the forward portion of the brain.

(2) The *parietal lobe* lies behind the fissure of Rolando, and extends posteriorly to the occipito-parietal fissure. The convolutions are well marked, and are separated by a well-marked sulcus (sometimes known as the intra-parietal fissure); and the posterior branch of the fissure of Sylvius is enfolded by an inferior parietal convolution, known as the "supramarginal convolution."

(3) The *temporo-sphenoidal,* or *temporal lobe,* is below the Sylvian fissure and in front of the occipital lobe. Its convolutions are well marked.

(4) The *occipital lobe* is found at the posterior end of the cerebral hemisphere, and its convolutions are continuous with those of the parietal and temporo-sphenoidal lobes, except within the longitudinal fissure, where it is cut off from the parietal by the parieto-occipital fissure.

FIG. 95.



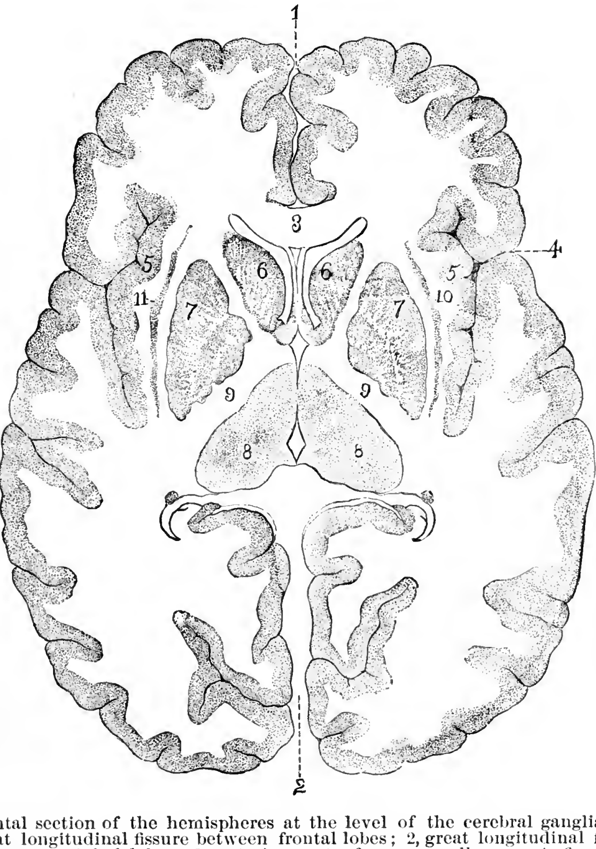
Plan of the human brain in profile, showing its fissures and convolutions. *S*, fissure of Sylvius; *S′*, anterior branch; *S″*, posterior branch; *R*, fissure of Rolando; *P*, intraparietal fissure.

(5) The *central lobe*, or *island of Reil*, is within the fissure of Sylvius, and is covered by convolutions of the frontal and parietal and temporal lobes (see 5 in Fig. 96).

Besides these well-defined lobes, the portion of the cerebral surface which is *within the longitudinal fissure* is marked by sulci and convolutions. Convolutions of the frontal, parietal, and occipital lobes are found here: the *marginal* convolution, the gyrus fornicatus lying above the corpus callosum, the paracentral lobule, the quadrate lobule, and the cuneate lobule are among the principal landmarks.

Arrangement of the gray matter: The increase in the area

FIG. 96.



Horizontal section of the hemispheres at the level of the cerebral ganglia. 1, great longitudinal fissure between frontal lobes; 2, great longitudinal fissure between occipital lobes: 3, anterior part of corpus callosum; 4, fissure of Sylvius; 5, convolutions of the insula; 6, caudate nucleus of corpus striatum; 7, lenticular nucleus of corpus striatum; 8, optic thalamus; 9, internal capsule; 10, external capsule; 11, claustrum.

of the surface of the hemispheres by the infolding of the sulci adds very greatly to the amount of gray substance in

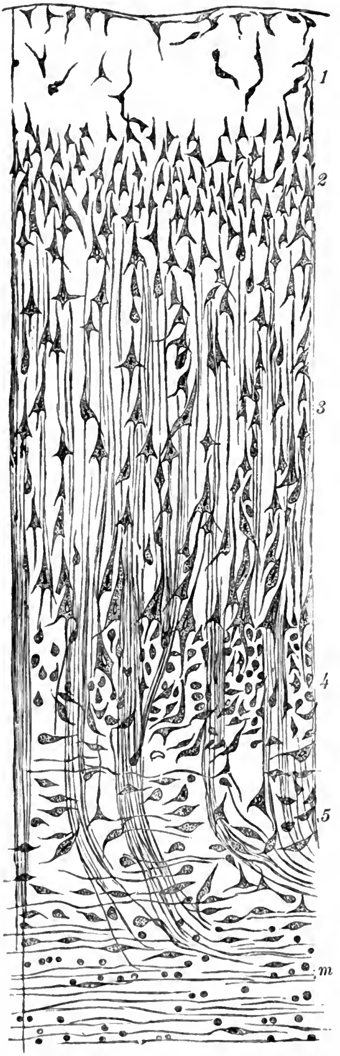


FIG. 97. Gray matter of the cerebral cortex (Meynert).

the brain; for the entire surface is composed of gray substance, and this follows the sulci and fissures (Fig. 96) in all their folds, and is not cut into by them.

Besides the gray matter in the convolutions, there are certain other gray masses in the substance of the white matter; the optic thalami, the corpora striata, and the claustrum (Fig. 96) are the chief of these gray masses.

Minute structure of the gray matter: The gray matter of the cortex is made up of ganglion-cells of various shapes and sizes lying in a loose neuroglia-stroma, more abundant at the surface. The cells are the source of numerous nerve-fibres, which pass out into the white matter (Fig. 97). There are counted five layers of these ganglionic tissues; and while these zones merge into one another, they are tolerably distinct. In the middle (and widest) layer large multipolar cells are very numerous, and the fibres may be seen to pass through the deeper layers in bundles into the white matter.

Chemistry of brain-tissue: Brain-tissue consists of some peculiar bodies allied to the fats, but containing nitrogen;

of these, *cerebrin* and *lecithin* are the more prominent. Aside from these, the constituents are proteid and fatty substances, with salts, chiefly potassium and magnesium phosphates, and water.

Weight of brain: About three pounds. In size it exceeds the brains of all the lower animals except those of the elephant and whale. Its weight is about one-fortieth of the total body-weight, and this ratio is greater than in the lower animals, with a few exceptions among the smaller birds and monkeys. In women the weight is about one-tenth less than in men.

Relation of size of brain to the intellect: In some degree the size of the brain bears a direct relation to the intellect of the individual, but this is not absolute. The depth of the sulci and the consequent size and complexity of the convolutions are a more efficient measure of the brain-power. In the largest of the apes the brain of an adult animal is about the same in weight as that of a human infant at birth. Idiots, as a rule, have brains much smaller than the normal, and in them the convolutions are apt to be ill-marked and uncomplicated, as is the case in the lower animals.

Course of the fibres in the hemispheres: The course of these fibres may be classified in three groups: 1, commissural fibres; 2, fibres of association; and 3, medullary fibres.

(1) The *commissural fibres* are those which connect one hemisphere with the other, and it may be said that these fibres connect each set of convolutions with the corresponding set of the opposite side. The convolutions of the portion of the brain lying above the fissure of Sylvius communicate by the corpus callosum.

(2) *Fibres of association* are those fibres which connect the convolutions of one hemisphere. These fibres pass in bundles just beneath the cortical gray matter of the convolutions, and it is thought that most of the important convolutions of each hemisphere intercommunicate in this way.

(3) The *medullary fibres* are those which connect the cerebrum and medulla, and are regarded as indirect and direct, according as they do or do not pass to the gray ganglia at the base of the cerebrum. In considering the course of the fibres

from the medulla through the crura cerebri it was noted that the motor and sensory fibres were to some extent separated. The fibres pass from the crusta to the internal capsule, and hence the "direct fibres" pass to the cerebral convolutions through the corona radiata; while the "indirect fibres" from the tegmentum pass to the corpora striata and optic thalami, and communicate with ganglion-cells in them.

Function of the corpora striata and optic thalami: These "basal ganglia," with the other collections of gray substance, seem to have a controlling influence upon the spinal system. It is through these ganglia that all voluntary impulses, except those by the direct medullary fibres, must pass. These basal ganglia communicate through the corona radiata with the convolutions of the cortex, and it is probable that we may regard this part as acting as a middleman to elaborate and coördinate the voluntary impulses of the cortex and to act in matters not requiring the intervention of the higher endowments of the mind. This status of these ganglia is quite theoretical, but the function may be considered as a sort having the properties of both the automatism of the gray matter of the medulla and cord and the voluntary function of convolutions. In this consideration, however, we must not undervalue the communication with the cortex which these basic ganglia possess.

Lesions of the basic ganglia: So far as has been observed, the corpora striata may be involved by considerable lesions without causing persistent motor or sensory disturbances, and the same may be said of the optic thalami; but if the lesion encroaches upon the white matter of the internal capsule, or crura cerebri, the effect is to cause more or less paralysis, depending upon the severity of the lesion and its position.

Functions of the cerebrum: The motor and sensory functions which have been seen to belong to other nuclei or gray matter are centred here, but infinitely broadened, for the cells in the convolutions of the cerebrum can originate the efferent and perceive the afferent nerve-impulses. In fact, it is in this portion of the brain that the intelligence is centred: it is the organ of the mind. Memory, reason, emotions, and all

the other attributes of the mind are dependent upon its functional power.

Unilateral action of the brain: There are instances in which injury or disease of one-half of the cerebrum has left the *intellectual* faculties not gravely impaired. From a consideration of such cases it has been held that the action of one of the hemispheres is sufficient for the purposes of the mind. There is, however, an absolute dependence for motor and sensory functions upon the integrity of both sides, for the one side cannot act for the other in these functions. As a rule, it is safe to assume that the hemispheres act in unison.

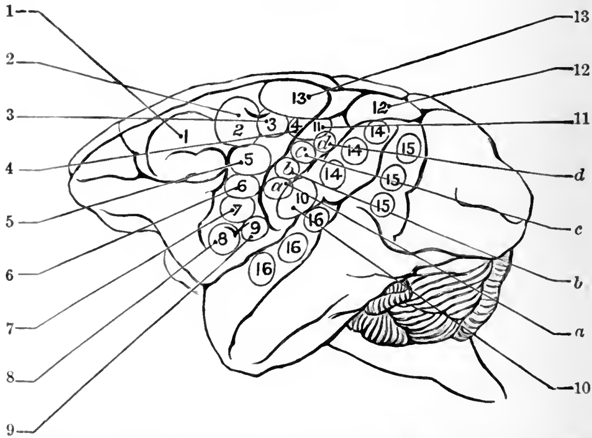
Localization of brain-function: While the brain is regarded as an organ of the mind, it is probable that the various functions may be regarded as belonging to definite portions of the convolutions which are appropriated for that purpose. The functions of the convolutions have not been assigned, except for a small portion of the brain-surface and for some of the simpler actions. For the most part, our knowledge of the exact localization of brain-functions is confined to "motor areas," in which it has been determined that stimulation of a certain group of cells will cause a definite action. Besides this, certain other centres are located, as of sight and speech.

Determination of motor areas: When the surface of the brain is exposed in animals or in man, the stimulation of certain areas of the cortex by a mild electrical current will give rise to motion in the peripheral muscles; and it is found that the stimulation of the same region in the same or other animals will cause the same results. These centres of motor impulses are situated almost entirely upon the convolutions about the fissure of Rolando (Fig. 98).

Sensory areas: These have not been, by any means, so definitely fixed as the motor centres; but the centres for sensation may be said to exist, and probably in the convolutions of the posterior portion of the cerebrum. The centre for *vision* in the convolutions about the posterior branch of the fissure of Sylvius is generally accepted; or in the cuneate lobule (14, 15, in Fig. 98). The centre for *hearing* is tolerably defined in the temporo-sphenoidal lobe along the posterior branch of this fissure (16, Fig. 98). The *speech*-centre

is also located with seeming accuracy along the anterior branch of the fissure of Sylvius and in the third frontal convolution. This centre seems to be much more developed upon the left side of the brain. In Fig. 98 this centre may be indicated roughly by reference to the tongue-centres (8 and 9).

FIG. 98.



Brain of monkey, showing the position of the motor and sensory centres as ascertained by Ferrier. The actions all occur on the side of the body opposite to the part of the brain irritated. 1, the eyes open widely, the pupils dilate, and head and eyes turn toward opposite side; 2, extension forward of the opposite arm and hand, as if to reach something in front; 3, movements of tail (and trunk); 4, retraction with adduction of opposite arm; 5, supination and flexion of the forearm, by which the arm is raised toward the mouth; 6, action of zygomatics, by which the angle of mouth is retracted and elevated; 7, elevation of ala of nose and upper lip; 8, opening of mouth with protrusion of tongue; 9, retraction of tongue; 10, retraction of opposite angle of mouth; *a, b, c, d*, prehensile movements; 11, retraction and adduction of opposite arm; 12, advance of the opposite hind limb; 13, complex movements of thigh, leg, and foot; 14, 15, vision (sensory); 16, hearing (sensory).

Pathological support of localization: Injuries and diseases involving the motor areas are followed by paralysis so well defined that it is frequently possible to locate the seat of the lesion from its result upon the muscular system. Tumors, abscesses, and depressed bone, for example, are capable of accurate localization in this way. The more indefinite sensory paralyses do not so accurately point out their origin. On the whole, the evidence of pathology bears out in full the experimental results. The crossed action of all the nervous

structures is especially to be noted. In the case of a right paralysis in which the speech is affected, as compared with a left hemiplegia and speech unaffected, this crossed action is impressed when we remember the localization of the centre for speech in the left hemisphere near the motor area.

Terms used in defining paralysis: Anæsthesia = loss of sensation.

Hemianæsthesia = loss of sensation in one lateral half of the body.

Hemiplegia = loss of muscular power in one lateral half of the body.

Paraplegia = symmetrical loss of muscular power in the lower portion of the body and extremities.

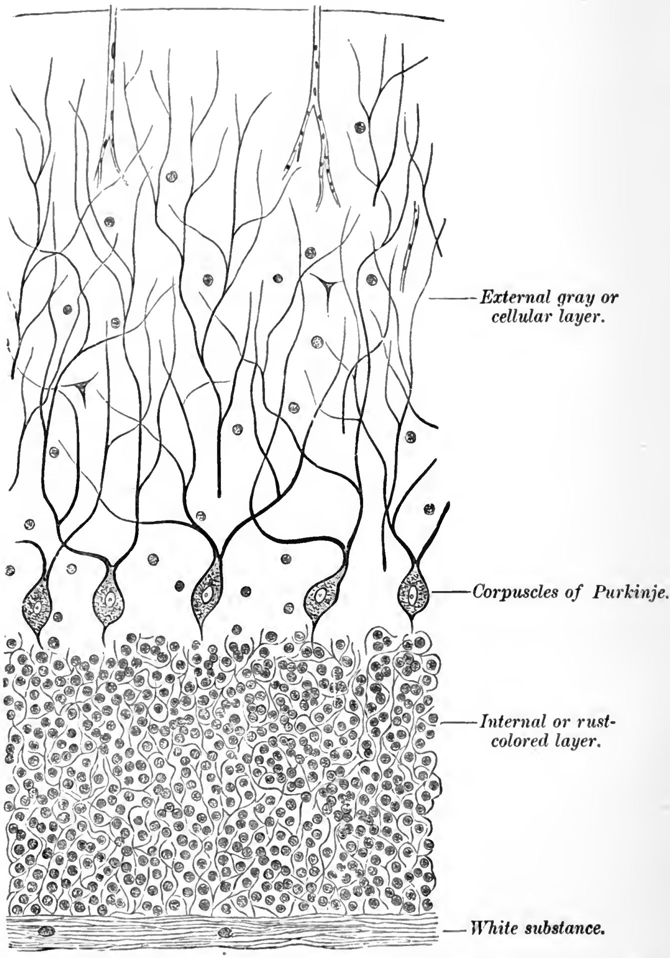
Aphasia = loss of power to talk: amnesic when words are forgotten; ataxic when the power to articulate is lost, though the words are known.

The Cerebellum.

The **cerebellum** is a mass of nerve-substance situated posteriorly at the base of the skull. It consists of a median lobe and two lateral hemispheres, and is connected with the rest of the cerebro-spinal system by numerous white fibres collected in bundles known as *peduncles.* Of these, the larger peduncles pass to and largely make up the pons Varolii (middle peduncles), thus connecting the lateral hemispheres of the cerebellum. The superior peduncles pass beneath the corpora quadrigemina, and the fibres pass into the cerebrum, decussating as they meet beneath the corpora quadrigemina. The inferior peduncles pass to the medulla, where they form the restiform bodies. Thus it is seen that the entire cerebro-spinal system communicates very freely with the cerebellum.

Arrangement of the gray matter: The arrangement in convolutions is not the same as in the cerebrum, but there are numerous transverse sulci which divide and subdivide, the gray matter being disposed about them in a thin layer. This causes a section of the organ to have a peculiar tree-like appearance, which originates the name, "arbor vitæ," given to these sections of the cerebellum. Besides this, there is a central collection of gray substance—the corpus dentatum.

Fig. 99.



Vertical section through the gray matter of the human cerebellum (magnified about 100 diameters: Klein and Noble Smith). Two branched capillaries are seen at the upper part passing into the gray matter from the pia mater.

Microscopic examination of gray matter: Under the microscope it is found to consist of three layers (Fig. 99). The

outer is a layer of delicate "connective tissue" which supports fine nerve-fibres and small spindle-shaped, branching nerve-cells. The middle layer is characterized by irregularly disposed large ganglion-cells, and the branching processes from these ramify in the superficial layer. These cells are known as *Purkinje's cells.* The inner layer is made up of a mass of small spheroidal cells, and gradually merges into the white substance.

Function of the cerebellum: The cerebellum seems to exert no influence upon the sensory nerves, for sensibility is not affected by its injury or disease. The motor system is, however, entirely disorganized by lesions of the organ. *Coördination* of the voluntary muscles is accomplished by this portion of the brain, and it is originated in the gray matter of the part. It has no effect upon the senses nor upon the intellect, so far as is known.

Tracts in Brain and Cord.

The **motor tract** consists of bundles of medullated nerve-fibres originating in cells of the motor area of the brain. These fibres pass downward, between the optic thalamus and caudate nucleus on the inner side and the lenticular nucleus on the outer side. During this part of their course the fibres form the *internal capsule.*

Passing down in the *crustæ*, the fibres reach the *pons.* Here the fibres change position, so that the *facial* fibres cross over from the inner side of one-half the motor tract so as to lie in the inner half of the opposite motor tract. The leg- and arm-fibres continue down in their respective positions without decussating among the ventral longitudinal fibres of the pons.

On leaving the pons the *face-fibres* pass out through the respective cranial nerves to the muscles of the face.

The *leg-* and *arm-fibres* enter the medulla and *decussate to the opposite side* as the *crossed pyramidal tract,* and run down as the "crossed" column of the cord (the lateral). A few fibres continue without decussating, in the anterior column (column of Türck), and are known as the *direct pyramidal tract.* Thence the motor fibres pass to various levels of the cord.

Lesions of the motor tract: From the definite anatomical course of the motor tract we may conclude that definite lesions

at any point of its course will give definite results. Such is the case. Naturally a lesion of the motor tract gives paralysis as a marked symptom. The particular nerves and the number involved assist us in locating the exact area of the tract affected.

1. *Lesions on the cortex* or in the *internal capsule* result in a variable amount of paralysis; but the paralysis is on the *opposite side* from the lesion.

2. *Lesions at the upper border of the pons* result in paralysis of the face on the *same side* of the body, but of the arm and leg on the *opposite side* from the lesion.

3. *Lesions below the decussation of the face-fibres* and above that of the arm and leg leave the face unaffected, but paralyze the arm and leg of the opposite side of the body.

Sensory tract: Starting with the posterior columns of the cord (columns of Goll and Burdach), the sensory fibres pass into the medulla as the funiculi graciles and cuneati. Here they decussate (decussation of the fillet) posterior to the median raphé. In the *pons* they form the straight fillet, ascending in the crura cerebri dorsally to the motor fibres (tegmentum). As part of the corona radiata, sensory fibres are then distributed to that portion of the cerebral cortex situated well behind the fissure of Rolando—*i. e.*, posterior parts of the parietal and occipital lobes. Their terminations are *end-arborizations* with sensory cells.

Mutilations.

Mutilation of brain: Numerous experiments have been conducted upon animals showing the effect produced on the animal of the removal of different parts of the brain. Thus we have learned by deduction the functions of many parts of the cerebro-spinal system. One of the simplest experiments, and one also frequently observed in surgery, is a division of the spinal cord.

Division of the spinal cord: The result is a complete loss of conductivity between the two segments of the cord, above and below the point of division. The manifestation is a loss of sensation, and paralysis of the parts supplied by nerves emerging from the cord at a point below the section. Only such reflexes are present in the affected parts as have their

seats in that portion of the cord (below the section) still in connection with the affected areas. The parts still in connection with the brain (above the section) retain their normal function. If the section be made between the medulla and the point of origin of the phrenic nerves, death from asphyxia results.

In a frog, whose spinal cord has been cut close to the medulla, and whose medulla has been destroyed, the following results are noticed: although the frog does not respire through his lungs, he still lives, as he absorbs oxygen through the skin, provided it be kept moist. The animal lies prone on its belly. If dropped into a basin of water, it sinks, making no attempt to swim; nor does it swallow food, even if placed on the tongue.

If the section be made anterior (above) to the medulla, the frog breathes, sits in a normal position, swims in a basin of water until it strikes a suitable landing, then crawls out and sits still. It makes no motion unless irritated, then hops away; and swallows food placed on the tongue.

Removal of the cerebellum: When small portions are removed the animals become feeble and uncertain in their movements, but are able to move for ordinary purposes. As the amount removed increases the want of coördination of the voluntary muscles increases. With the entire cerebellum gone the condition is absolute—animals cannot stand nor walk, nor bring any of the muscles into orderly action. If the animal is laid upon the back, it cannot recover itself, but struggles vaguely in the attempt. The senses are apparently normal and the will-power is present: if a blow is threatened, an attempt is made to avoid it. When the lesion is confined to one hemisphere, the lack of coördination is noticed in the opposite half of the body. Under these circumstances the animals are apt to fall to the opposite side and roll over and over rapidly. Such movements are known as *forced movements.* This condition may persist for several days. Pigeons from which the cerebellum is removed may live for a considerable time, sometimes for several months, after the operation. In some cases there is a return of power to coördinate, after partial removal, at the end of some days.

Removal of the cerebral hemispheres: In some of the lower animals the cerebrum may be entirely removed without killing them. When this is done, for example, in the case of a pigeon, the bird remains quiet in one position, and is not disturbed by noises; or if thrown from its perch, it flies and alights in a nearly normal manner. If a foot be pinched, it withdraws it and perhaps changes its position. The bird is capable of reflex actions of various complicated kinds, but there is no spontaneous exercise of volition: all its movements are excited by the nerve-stimuli of the moment. There is no perception of stimuli; the intelligence is gone.

Cranial Nerves.

The **cranial nerves** are a set of twelve pairs of nerves which arise from the brain. They are varied in their functions, but all arise from ganglia of the gray matter in the brain and medulla. The floor of the fourth ventricle is particularly rich in nuclei in which these cranial nerves originate.

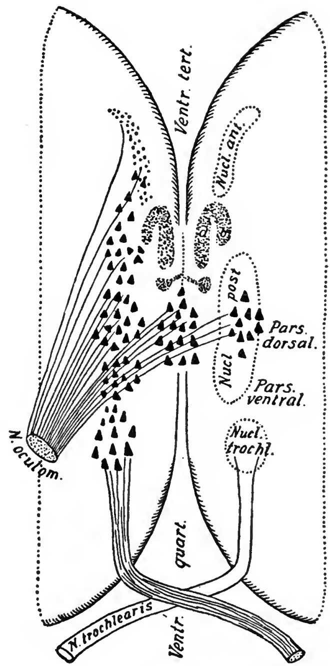
Classification of the cranial nerves: In the order of their emergence, by numbers: (I) olfactory; (II) optic; (III) motor oculi; (IV) patheticus; (V) trigeminus; (VI) abducens; (VII) facial; (VIII) auditory; (IX) glosso-pharyngeal; (X) pneumogastric; (XI) spinal accessory; (XII) hypoglossal. In the relation of their functions they may be arranged as nerves of special sense, nerves of common sensation, motor nerves, and mixed nerves (*i. e.*, sensory and motor).

Nerves of special sense,	(I) olfactory, (II) optic, (VIII) auditory and parts of the (V) trigeminus and (IX) glosso-pharyngeal.
Nerves of common sensation,	The greater portion of the (V) trigeminus.
Motor nerves,	(III) motor oculi,(IV) patheticus, (V) lesser division of the trigeminus, (VI) abducens, (VII) facial, and (XII) hypoglossal, (XI) spinal accessory (?).
Mixed nerves,	(IX) glosso-pharyngeal and (X) pneumogastric.

Of the nerves of special sense, (I) olfactory, (II) optic, and (VIII) auditory will be explained later, and may be omitted from further consideration for the present.

III nerve: It arises from a nucleus of gray matter just in front of the pons beneath the iter e tertio ad quartum ventriculum (aqueduct of Sylvius), passing out through the crus cerebri, and emerging from the skull in the orbit (Fig. 100). It gives off some fibres to the lenticular ganglion. It is distributed to all the muscles of the eyeball, with the exception of the superior oblique and the external rectus muscles. It also supplies the levator palpebræ superioris muscle, and by its connection with the lenticular ganglion controls the ciliary and pupillary muscles.

Fig. 100.



A partly diagrammatic view of the floor of the aqueduct, looking upward (dorsally), nuclei of the third and fourth nerves, and the decussating fibres of the latter all shown; the third nerve nuclei are subdivided into an anterior nucleus, the Edinger-Westphal nucleus (*a* and *b*), and a posterior nucleus; the posterior nucleus has a dorsal, a ventral, and a mesal portion; the decussation of the fibres from the dorsal portion of the posterior nucleus of the third nerve is shown (Edinger).

It is purely a motor nerve. Its function is best described by showing the paralyses which follow its division: by paralysis of the elevator of the upper lid we have *ptosis;* by paralysis of the muscles of the eyeball we have inability to move the organ up or down or inward; by the unopposed action of the external rectus the eyeball becomes turned outward (external strabismus); by paralysis of the muscle of the iris the pupil remains dilated and does not respond to

light; and by paralysis of the ciliary muscle the accommodation of the lens for near vision is prevented.

The control of the pupil is not a voluntary one; but the effect of a strong voluntary effort, exerted through the third nerve, shows itself in contraction of the pupil, as when the eyeball is turned strongly inward and upward.

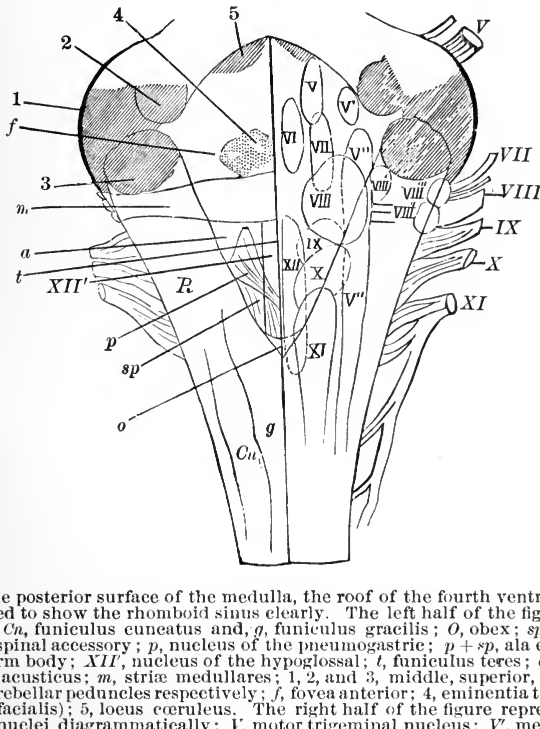
IV nerve: It arises close by the third nerve beneath the aqueduct of Sylvius, and emerges, after decussation, from the valve of Vieussens. Thence, passing around the crus cerebri, it runs parallel with the motor oculi (third) nerve to the orbit, where it is supplied to the superior oblique muscle. Its paralysis prevents the muscle from maintaining the horizontal plane of the eyeball. If this paralysis occurs, there is double vision, and the image seen by the affected eye appears oblique and inferior to the image of the other eye. This may be corrected by inclining the head to the opposite side. This nerve is also known as the *trochlearis* or *trochlear nerve*.

V nerve: This nerve resembles the spinal nerves in having a motor and a sensory root, the latter possessing a ganglion (Gasserian). The origin of the nerve seems to be in centres, separate for motor and sensory, in the floor of the fourth ventricle (Fig. 101). There are fibres which join the trunk of the nerve which are derived from the spinal cord. It emerges from the pons Varolii as two distinct nerve-roots. The larger of the two, the sensory, soon enters the Gasserian ganglion, the motor root passing beneath without communication. The nerve then breaks up into three branches: of these the first and second are formed entirely from the sensory root, while the third carries all the motor fibres, and with them some of the sensory, so that the third branch of the nerve is partly sensory and partly motor. There is a partial decussation of the fibres in the medulla, but many pass direct to the same side.

Muscles supplied by the motor root, V nerve: The muscles supplied are those of mastication. The temporal, masseter, and both pterygoid muscles, as well as the anterior belly of the digastric muscle and the mylo-hyoid, receive their innervation from the motor root of the fifth nerve. Besides this, the tensor palati and tensor tympani muscles are supplied

by this nerve through its communication with the otic ganglion of the sympathetic system. A branch to the buccinator

FIG. 101.



View of the posterior surface of the medulla, the roof of the fourth ventricle being removed to show the rhomboid sinus clearly. The left half of the figure represents: *Cn*, funiculus cuneatus and, *g*, funiculus gracilis; *O*, obex; *sp*, nucleus of the spinal accessory; *p*, nucleus of the pneumogastric; *p* + *sp*, ala cinera; *R*, restiform body; *XII'*, nucleus of the hypoglossal; *t*, funiculus teres; *a*, nucleus of the acusticus; *m*, striæ medullares; 1, 2, and 3, middle, superior, and inferior cerebellar peduncles respectively; *f*, fovea anterior; 4, eminentia teres (genu nervi facialis); 5, locus cœruleus. The right half of the figure represents the nerve-nuclei diagrammatically: *V*, motor trigeminal nucleus; *V'*, median and, *V''*, inferior sensory trigeminal nuclei; *VI*, nucleus of abducens; *VII*, facial nucleus; *VIII*, posterior median acoustic nucleus; *VIII'*, anterior median; *VIII''*, posterior lateral; *VIII'''*, anterior lateral acoustic nuclei; *IX*, glosso-pharyngeal nucleus; *X*, *XI*, and *XII*, nuclei of vagus, spinal accessory, and hypoglossal nerves respectively. The Roman numerals at the side of the figure, from *V* to *XII*, represent the corresponding nerve-roots (Erb).

muscle is probably not motor, but sensory. *Lesions* of the nerves paralyze these muscles.

The **sensory fibres** of the fifth nerve are distributed in all three branches, and supply sensation to the skin of the face

and anterior portion of the head, emerging from the bony canals upon the face at the supraorbital, infraorbital, and mental foramina. Sensory fibres are also supplied to the mucous membrane of the mouth and tongue (by the lingual branch) and to the muscles of the part (Fig. 102).

FIG. 102.

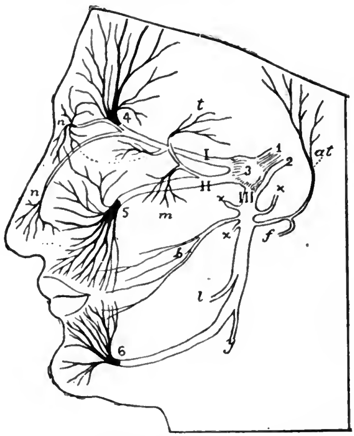


Diagram of the fifth nerve and its distribution. 1, sensitive root; 2, motor root; 3, Gasserian ganglion: I, ophthalmic division; II, superior maxillary division; III, inferior maxillary division; 4, supraorbital nerve, distributed to the skin of the forehead, inner angle of the eye, and root of the nose; 5, infra-orbital nerve, to the skin of the lower eyelid, side of the nose, and skin and mucous membrane of the upper lip; 6, mental nerve, to the integument of the chin and edge of the lower jaw, and skin and mucous membrane of the lower lip; *n*, *n*, external terminations of the nasal branch of the ophthalmic division, to the mucous membrane of the inner part of the eye and the nasal passages, and to the base, tip, and wing of the nose; *t*, temporal branch of the superior maxillary division, to the skin of the temporal region; *m*, malar branch of the superior maxillary division, to the skin of the cheek and neighboring parts; *b*, buccal branch of the inferior maxillary division, passing along the surface of the buccinator muscle, and distributed to the mucous membrane of the cheek and to the mucous membrane and skin of the lips; *l*, lingual nerve, to the mucous membrane of the anterior two-thirds of the tongue; *at*, auriculo-temporal branch of the inferior maxillary division, to the skin of the anterior part of the external ear and adjacent temporal region; *x*, *x*, *x*, muscular branches, to the temporal, masseter, and internal and external pterygoid muscles; *y*, muscular branch, to the mylo-hyoid and anterior belly of the diagastric; *f*, sensitive branch of communication to the facial nerve.

Destruction of the sensory root results in complete anæsthesia of the skin of the face and mucous membrane of the mouth.

The *trophic influence* of the sensory root is of very great value. If it be divided, the complete anæsthesia of the conjunctiva, of the nostrils, and of the lips prevents the reflex self-protection which belongs to the parts, and they become injured very easily. Aside from that, the direct influence upon all the parts is great, so that when it is cut off there is a rapid degeneration resulting, which is specially apparent in the mucous membrane of the nose and in the cornéa.

Influence of the sensory branch on the special senses: (1) Its division causes total anæsthesia to the skin and mucous membrane; the loss of the sense of *touch* in the part is of great importance, for the tongue and lips are used much for this purpose. (2) Upon the sense of *sight* it has a very controlling influence, for, as we have seen, the trophic influence is essential to the maintenance of the integrity of the eye. (3) Upon the sense of *smell*. Here the influence is the same as with the eyes, trophic. The smell is soon lost on account of degeneration of the mucous membrane after division of the fifth nerve. (4) *Taste*, probably, is not a direct function of the nerve; but if the tactile sensibility is gone and the trophic changes are begun, the sense of taste soon disappears in the anterior portion of the tongue. (5) Upon the *hearing* the effect is more gradual and less distinct. The secretions of the cavity of the tympanum and of the external auditory canal are of great importance in maintaining normal conditions. They are under the trophic influence of the fifth nerve, both through its auriculo-temporal branch and through its communication with the otic ganglion. The tensor tympani muscle is also supplied by the motor root. Thus, the auditory apparatus is considerably under the control of the nerve.

Symptoms due to pathological changes in the sensory root: Headaches of the scalp and deeper tissues, and more especially the frontal sinuses, are common. Toothache and facial neuralgia are due to irritation or disease of parts of the nerves. *Tic douloureux* is a persistent neuralgia of some or all of the branches of the nerve.

VI nerve: It arises from a nucleus of gray matter in the floor of the fourth ventricle, and its nucleus is more or less directly connected with those of the third, fourth, and seventh

nerves. It emerges without decussation at the posterior border of the pons Varolii, and passes forward to the orbit with the third and fourth nerves. In its course it has many communications with the sympathetic nerves, but their significance is unknown. It is supplied to the external rectus muscle of the eye, and its stimulation causes external squint, and paralysis causes internal.

VII nerve: It arises in the floor of the fourth ventricle, and its fibres emerge from the upper part of the groove be-

FIG. 103.

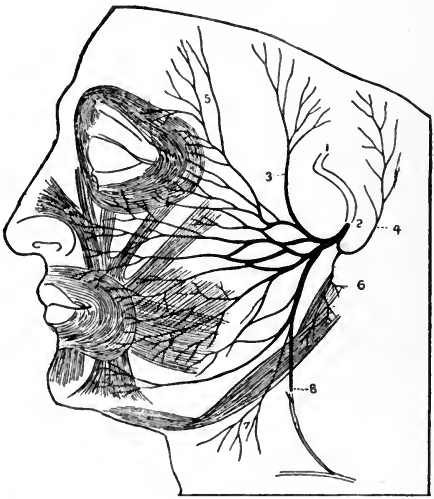


Diagram of the facial nerve and its distribution. 1, facial nerve at its entrance into the internal auditory meatus; 2, its exit at the stylo-mastoid foramen; 3, 4, temporal and posterior auricular branches, distributed to the muscles of the external ear and to the occipitalis; 5, branches to the frontalis muscle; 6, branches to the stylo-hyoid and digastric muscles; 7, branches to the upper part of the platysma myoides; 8, branch of communication with the superficial cervical nerve of the cervical plexus.

tween the olivary and restiform bodies in company with the (eighth) auditory nerve (sometimes known as the portio mollis; the facial being then called the portio dura of the "seventh" pair, when the classification of the cranial nerves is made into nine pairs). It passes into the internal auditory

canal, and escapes from the skull by way of the aqueduct of Fallopius and the stylo-mastoid foramen.

It is almost wholly a motor nerve, and is distributed to all of the muscles of the face (Fig. 103) except those mentioned as controlled by the motor branch of the trigeminus nerve. The muscles of the eyelids and some of the muscles of the palate in part are innervated by it, as well as the parotid and submaxillary glands through the chorda tympani. In the neck it supplies the posterior belly of the digastric and the platysma myoides muscles. It also sends branches to the stapedius muscle of the internal ear and to all of the muscles of the external ear. The branches passing to the salivary glands are *secretory* in their function; and this is the only exception to the motor influence of the nerve.

Function of the VII nerve: It is the motor nerve which parallels in its distribution the sensory root of the fifth; it supplies the superficial muscles, as the latter does the skin. It is the nerve of "expression," by which the features are made to reflect the emotions.

Paralysis of the VII nerve: If the nerve be divided or diseased, the face of that side is devoid of motion (Fig. 104), and becomes smooth and expressionless, while the sound side is held in its customary pose. The eyelids cannot close themselves, and the lips do not oppose properly, on account of the defective action of the orbicular muscle. There is difficulty in drinking and in articulation for the same reason.

The eyelids remain open in facial paralysis, and the conjunctiva is subject to injury by drying and by foreign bodies; but the injury is not so great as in paralysis of the fifth nerve, because the seventh has no trophic influence.

Chorda tympani branch: The chorda tympani is a small filament given off from the facial in the aqueduct of Fallopius, some of whose fibres are distributed to the submaxillary gland. If this nerve be divided, the secretion of saliva from the gland is greatly diminished, while stimulation of the nerve will excite a copious flow. This is an active secretion, and is not a simple filtration due to vaso-motor changes. A similar influence is noted in the corresponding half of the tongue.

There is a similar distribution of fibres from the facial to the parotid gland, which also receives secretory fibres from the glosso-pharyngeal through the lesser superficial petrosal

Fig. 104.

Facial paralysis of the right side.

nerve, but their action has not been so thoroughly analyzed as in the case of the submaxillary and chorda tympani.

The chorda tympani has still further an effect upon the sense of *taste* in the anterior portion of the tongue. If it be divided, the taste is much blunted on the affected side. It is

now known that this is due to the communication with the glosso-pharyngeal nerve, thus: the chorda tympani has fibres from the otic ganglion, which, in its turn, receives the lesser superficial petrosal nerve from the glosso-pharyngeal.

IX nerve: It arises in the medulla from centres near those for the vagus and spinal accessory nerves. Its fibres pass through the substance of the medulla and emerge in company with those of the vagus and spinal accessory, to pass with them from the skull through the jugular foramen. It gives off a small branch, which passes to the tympanum and Eustachian tube (Jacobson's nerve) while in the jugular foramen, and presents a small ganglion, the petrosal; and it has communicating branches to the seventh and tenth nerves and to the otic ganglion.

The nerve divides as it passes down, one branch passing forward to the tongue, and one going to the pharynx (whence its name).

The portion which passes to the *tongue* is distributed to the posterior portion of the organ, to the circumvallate papillæ, and the mucous membrane behind them, some fibres going to the lining of the soft palate, pillars of the fauces, and tonsils. The other branch is distributed to the mucous membrane of the *pharynx*, and by direct branches and communication with other nerves to all the muscles involved in swallowing.

Function of the IX nerve: (1) It is the nerve of *taste;* and (2) it is essentially a nerve of deglutition.

(1) It is only in the latter part of the stay of food in the mouth that it reaches the region directly supplied by this nerve. When the food is to be swallowed, it is pressed by the base of the tongue against the palate arch and pushed into the pharnyx. It is then that the sense of taste is here exercised. The reflex stimuli then excited start up the motor chain, which pushes the bolus on to the stomach. At one time there was considerable question as to whether the trigeminal or glosso-pharyngeal was really the conductor of this sense, but it is quite likely that both are essential to its proper appreciation.

(2) Whether by reason of its communications with other nerves or not, in its distribution the nerve is a motor nerve as

well as sensory. Its distribution is to all the muscles of deglutition, and stimulation causes contraction of the muscles, while division paralyzes them. The very numerous connections of the nerve complicate its anatomical origin very greatly, and interfere with a clear comprehension of the unaided function of the nerve.

The *reflex for swallowing* originates in the medulla oblongata, where the origin of the nerve is situated.

X nerve: The Xth nerve is also known by two other names: "pneumogastric," from its distribution and function; "vagus" or "par vagum," from its scattered distribution (vagus, Latin, wanderer).

It arises from the gray matter in the floor of the fourth ventricle, its nucleus being very close to those of the glosso-pharyngeal and spinal accessory. Its fibres pass through the substance of the medulla oblongata, and emerge from its lateral surface with the roots of its associate nerves, the glosso-pharyngeal, and spinal accessory. It passes from the skull with them by the jugular foramen. It has at this point a ganglionic enlargement. From here it passes down the neck, and is distributed more diffusely than any other cranial nerve.

It is supplied to the organs by which air and food enter the body, and besides this has several important connections with the sympathetic system. (1) To the larnyx it supplies sensation and motion through the superior and inferior *laryngeal branches.* (2) In the chest it forms the *pulmonary plexuses,* which innervate the bronchi and lungs. (3) Branches to the cardiac plexus supply important stimuli to the heart and great vessels. (4) There are branches to the *pharyngeal* and *œsophageal* plexuses which are both sensory and motor, supplying both the mucous membrane and the muscular structures of the parts. (5) Its terminal branches supply the sensory and motor nerves to the stomach, the left nerve being distributed on its anterior wall, and the right posteriorly. (6) Branches also pass to the liver and spleen and communicate with the solar plexus.

Communication between X nerve and other nerves: Soon after leaving its origin in the medulla the vagus enters into

so many communications with other nerves, both sensory and motor, that it is difficult to know the real fibres of the original root and to determine what are original and what derived functions. The sympathetic system sends fibres in all the branches of the pneumogastric, and the pneumogastric sends branches to many of the important sympathetic plexuses and ganglia; the pharyngeal, laryngeal, œsophageal, pulmonary, cardiac, and solar plexuses are so made up by branches from both. The spinal accessory nerve is an important contributor, in that it sends a large branch which is incorporated in the vagus. The fibres from the spinal accessory nerve are motor, and are, most of them, carried in the recurrent laryngeal nerve. There are also communications to the glosso-pharyngeal and hypoglossal nerves, and it also receives motor fibres from the facial and upper two cervical nerves.

The original nerve is probably entirely sensory, and its *motor* function is derived from these connections with motor nerves.

Function of X nerve in respiration: The nerve supplies, as has been said, the motor and sensory functions of the larynx, and in this is of value to the respiratory function both in the prevention of foreign substances entering the rima glottidis, and in the opening of that orifice for the entrance of air. Besides this, it supplies sensory fibres to the pulmonary plexus which transmit the reflex stimulus to the medulla, by which the motor apparatus is excited to action.

The muscles of the larynx involved in the production of sound are supplied by this nerve, and, as the approximation of the chordæ vocales is necessary for this, it follows that the voice is dependent upon the fibres of the pneumogastric supplied by the inferior or recurrent laryngeal nerve.

Effect of section of X nerve on respiration: *Respiration* is slowed immediately to about half its usual rate, and soon drops to five or six to the minute, and even slower. The respiration is easy—inspiration slow and full, expiration harsh and sudden. Death follows this operation in a short time (one to six days), and the animal during the time is sluggish and apparently suffers from slow carbonic-oxide

narcosis. It is inferred from this that the vagus is the nerve which carries to the automatic centre the stimuli which are needed to keep up the automatism, and that the medulla is incapable of originating the motor impulses unless controlled by afferent stimuli.

Function of X nerve in deglutition: *Deglutition* both in the pharynx and the œsophagus is under the influence of the vagus, which gives innervation directly to the thoracic part of the latter and through the inferior laryngeal branch to the cervical part. The sensory fibres act as conductors of the stimulus which results in the reflex peristalsis by which the food is carried on through the œsophagus. The sensory distribution to the larynx must not be forgotten in this connection, for by it food is kept from the respiratory organs. Section of the vagi causes paralysis of swallowing, and food is apt to pass the glottis on an attempt to swallow, not even a cough being excited by such an accident. The closure of the glottis in swallowing is caused by a reflex action known as the "action of arrest," and is derived from the sensory fibres of the vagus.

Relation of X nerve to stomach: The stomach receives both motor and sensory function through the vagus. The stomach receives its warning of the presence of food through the sensory fibres, and the muscular fibres excite the organ to contract upon it and "churn" it about during digestion. There is also a vaso-motor influence derived from the vagus. When the nerve is cut but little food can reach the stomach, because of the paralysis of the œsophagus, and what food does enter is digested very slowly, so that the function of the pneumogastric may be considered essential to stomach digestion. The connection with the solar plexus also involves the intestines in the action of the vagus.

Influence of X nerve on the heart: There are numerous branches to the cardiac plexus from the trunk of the vagus and from its inferior laryngeal branch. Stimulation of the pneumogastric nerve diminishes the frequency, or, if strong, entirely stops the heart in diastole. The nerve is therefore regarded as having an *inhibitory action*. This is an unusual effect, for in other cases the stimulation of nerves going to

muscles causes contraction: the heart, however, becomes flaccid under the influence of the stimulated vagus.

Other functions of X nerve: The vagus nerve is the channel for excito-motor reflexes in coughing and vomiting, as well as for many other less essential reflexes, such as sighing, hiccoughing, and the like.

XI nerve: The origin of the XIth nerve is twofold. One root arises in the gray matter of the medulla near the nucleus for the vagus, while the other arises from the lateral tract of the cord as low as the fifth or sixth cervical vertebra, and passes up between the anterior and posterior spinal nerve-roots to join the medullary (or accessory) portion at its emergence from the medulla. The united nerve soon divides and passes out through the jugular foramen with the glosso-pharyngeal and pneumogastric nerves, the medullary portion joining the trunk of the pneumogastric, while the spinal root supplies the sterno-mastoid and trapezius muscles.

Function of XI nerve: The nerve is a motor to all intents, though it has some sensory fibres, as is shown by the pain caused by pinching it.

(1) The *anastomatic branch*, which joins the pneumogastric, is apparently largely given off in the recurrent laryngeal nerve; but its section does not produce the same effect upon the larynx as section of the trunk of the vagus or of its inferior laryngeal branch. There is paralysis of the voice, but not of the movements of the glottis for respiration. There are probably some fibres of this nerve also given off to the cardiac plexus.

(2) The *muscular branch* supplies the sterno-mastoid and trapezius muscles; but these muscles are also supplied by the cervical spinal nerves, and their action is not paralyzed by the section of this branch of the spinal accessory. It is found, however, that the relation of these muscles to respiration is impaired by isolation from this nerve—that is, when the breath is held in any violent exertion, as straining or pushing, or when a loud cry is uttered, the sterno-mastoid and trapezius muscles contract to fix the head and hold the spine steady. This action seems to be prevented by the section of this muscular branch of the spinal accessory.

XII nerve: It arises in the gray matter at the inferior extremity of the floor of the fourth ventricle, mesial to the origin of the spinal accessory and pneumogastric nerves. The fibres pass through the substance of the medulla oblongata, between the pyramid and the olivary body, and, emerging in a number of small bundles, connect into a nerve-trunk which emerges from the skull by the anterior condyloid foramen. It passes down the neck to about the level of the hyoid bone, where it curves forward and into the tongue, giving off branches to the muscles which move that organ.

Function of XII nerve: It is a motor nerve, but possesses some sensory fibres derived from the cervical spinal nerves and from the trigeminus, with whose lingual branch it inosculates on the side of the tongue. Filaments from it are distributed to all the muscles which move the tongue, and to the depressors of the hyoid bone through its *descending* branch.

The latter branch, although in the anatomical sheath with the hypoglossal nerve, is *not* an integral part of the nerve, but is derived from the upper cervical nerves.

Influence of XII nerve on digestion: It is important in mastication, for its muscles move the food about for the better action of the teeth. In animals, after division, drinking is impossible, because they are unable to lap up fluids, and the food is swallowed with difficulty because it is not carried back into the pharynx by the tongue after mastication.

Connection of XII nerve with speech: *Articulation* of most sounds involves movements of the tongue. Impaired articulation is an early symptom in bulbar or glosso-labio-laryngeal paralysis.

THE SENSES.

A peripheral organ for the reception of an impression, a nerve for its conduction, and a centre in the brain for the perception, are the **organs necessary for sensation.** It is by means of impressions so received and conducted to it that the mind is able to control the body and to take cognizance of the external world.

Classification of sensations: *Common sensations* and *special sensations.* These last are commonly called "the senses."

Common sensations: Such perceptions as cannot be distinctly located in any organ or set of organs, such as fatigue, hunger, thirst, satiety. Besides these, there are some sensations which involve certain organs which must be classed under this head; thus inclinations to cough or to sneeze or to vomit are common sensations, and, similarly, to urinate or defecate. Many of these sensations occupy a border-line between common sensibility and the special sense of touch, such as itching and tickling.

Pain is a common sensation, but is very closely allied to the sense of touch. The two may be differentiated, however. If one touch a sharp instrument, he may perceive its shape and condition; but if the pressure be increased, the ability to perceive its form is lost, and instead the sensation of pain is established. The relation of the two is curiously shown in partial anæsthesia by drugs, as when one takes nitrous-oxide gas for the extraction of a tooth, and is able to feel the operation and to know what has been done, without in the least feeling pain.

The **seat of the senses** is the brain, or *sensorium.* The organ of the mind, which perceives the thing which the organ of sense has taken an impression from, is the fundamental structure in the necessary chain.

Hallucination is the *perception* of an object as a *real presence* without the presence of the object to justify the perception; that is, it is an act of the brain which refers its action to an organ of the senses. Thus, in delirium tremens a person may perceive many curious and uncanny things, which his mind hears and sees and feels, but which his senses could not take cognizance of, because they are only "creatures of the mind."

Difference between common and special sensations: The most important distinction between common and special sensations, is that the former are strictly limited to the condition of our bodies, while by the latter we gain, in addition, information respecting affairs outside of our bodies. This difference may be explained if we compare the sensations of pain

and touch, the one a common, the other a special sensation. For example, if the point of a needle be gently pressed against the tip of the finger, we only feel this point by our sense of touch and refer the sensation to the object causing it. But if the needle be pressed harder, so as to enter the skin, we feel at once a sensation of pain, which is no longer referred to the needle, but to the finger itself. The sensation of pain is not able to cause us to recognize the object which caused it, nor its nature.

Sensations and perceptions: Our habit of referring sensations to outside causes leads us to consider as *properties* of external bodies the sensations which they excite in us. When we speak of anything as having a bad taste, we forget that it only tastes bad to us. This habit pertains especially to sensations of touch and sight. From constant exercise of it we finally come to believe implicitly in the "evidence of our senses."

Judgments: There is a distinction between a sensation and a judgment (which is often unconsciously based on sensations). When we estimate the distance of an object from ourselves we form a judgment based on past experience of many sensations, such as the number of steps we must take before we touch it, etc.

Nerves of special sense: The special nerves have no other function than the special one for which they are set apart; and when they are separated from their special organs for receiving impressions, they no longer respond to the customary stimuli. The special senses are *touch*, *taste*, *smell*, *hearing*, and *sight*.

Touch.

The **organ of touch** consists of the skin and mucous membranes adjoining it. The nails and teeth too exercise a peculiar function in this regard, and the hair in some regions—*e. g.*, eyelashes. Touch is really only a specialized development of common sensation or sensibility. The sensations of touch, therefore, are conveyed to the central nervous system by those nerves which confer ordinary sensation on the differ-

ent parts of the body—that is, the sensory cerebral nerves and those arising from the posterior roots of the spinal nerves. By means of the sense of touch we acquire knowledge of the size, shape, and other external peculiarities of bodies.

Varieties of touch: (1) Tactile sensibility, or touch proper; (2) the sense of pressure or weight; (3) the sense of temperature. All of these, when carried beyond moderate limits, are merged into the sensation of pain.

Acuteness of touch: The *distribution of the end-organs* of the sensory nerves varies in different parts of the body, and the more numerous the touch-corpuscles, the more acute the sensibility of the part. Again, the *thickness of the epidermis* has marked influence in determining the tactile ability, portions of the hands and feet, when callous, having very blunted sensibility. The hardness and elasticity of bodies, the quality of the surface as to smoothness, the size and form and the temperature, and wet or dry condition, are all easily determined by touch.

The *hand* is of great value as an organ of touch because of the acuteness of its sensibility. Further than this, the hand is so constructed as to be capable of forming impressions of bodies by reason of its power to grasp them and to test them as to weight.

Measure of acuteness of touch is by means of a pair of compasses whose points are blunted. The legs of the instrument are separated, and the distance between the points which can just be distinguished as two separate contacts, measures the sensibility. From the accompanying table it will be seen that the touch is most acute in the tip of the tongue and in the fingers and tips, while in other portions the sense of touch is so vague that two points of contact are not distinguished until they are two and a half inches apart. It is found that the points of the compasses must be more widely separated when the test is made in the long axis of a limb than when across it (the table is from Kirke's *Handbook*):

Table of Variations in the Tactile Sensibility of the Different Parts.—(The measurement indicates the least distance at which the two blunted points of a pair of compasses could be separately distinguished.—E. H. Weber.)

Tip of tongue	$\frac{1}{24}$	inch.
Palmar surface of third phalanx of forefinger	$\frac{1}{12}$	"
Palmar surface of second phalanges of fingers	$\frac{1}{6}$	"
Red surface of under lip	$\frac{1}{6}$	"
Tip of the nose	$\frac{1}{4}$	"
Middle of dorsum of tongue	$\frac{1}{3}$	"
Palm of hand	$\frac{5}{12}$	"
Centre of hard palate	$\frac{1}{2}$	"
Dorsal surface of first phalanges of fingers	$\frac{7}{12}$	"
Back of hand	$1\frac{1}{6}$	"
Dorsum of foot near toes	$1\frac{1}{2}$	"
Gluteal region	$1\frac{1}{2}$	"
Sacral region	$1\frac{1}{2}$	"
Upper and lower parts of forearm	$1\frac{1}{2}$	"
Back of neck near occiput	2	"
Upper dorsal and mid-lumbar regions	2	"
Middle part of forearm	$2\frac{1}{2}$	"
Middle of thigh	$2\frac{1}{2}$	"
Mid-cervical region	$2\frac{1}{2}$	"
Mid-dorsal region	$2\frac{1}{2}$	"

The sense of touch may be greatly educated and specialized. This is seen in many of the arts where great dexterity obtains by reason of an educated touch. The reading raised letters by the blind is a familiar example of educated touch.

Pressure-sensation: When *weight* is added to an ordinary touch the sensation of the pressure of the weight is felt, and by it one can judge with considerable accuracy the amount of the pressure, and determine the comparative pressure of two weights with approximate correctness within limits of pressure. This is known as the sense of pressure.

Muscular sense: By taking a body in the hand and raising it we feel a sense of resistance in the muscles, by whose intensity we can much more accurately determine the weight. This is the *muscular sense.* It is developed to an exceedingly fine degree in some occupations; for example, postal clerks detect overweight letters with wonderful accuracy and quickness.

It has been urged that the muscular sense is of central origin, and depends upon the strength of the impetus which must be sent to the muscles to cause them to do certain work. It may, however, be due to a training of the sensibility of the muscle, whereby the relative strength of a contraction is perceived as a sensation. The *centre* for muscular sense is in the upper part of the quadrate lobule on the mesial surface of the hemisphere. Its involvement by pressure brings about inability to locate the position, say, of hand or foot without the aid of *sight.* Thus, the individual can *move* his upper extremity; but if the hand is placed out of range of vision, he does not know *where it is.*

Temperature-sense: The surface of the body is very sensible of temperature-changes; and that this is distinct from ordinary tactile sensation has been inferred from the fact that when the ordinary touch is blunted the temperature-sense may remain unimpaired. Temperature-sensations are not accurate; they are only relative—that is, we infer from the temperature of the skin or of our habitual surroundings the warmth or coldness of the thing tested. It is related that Arctic explorers have found the water feel warm when swimming in pools on icebergs, and a drop of the mercury to 80° F. is said to feel cold in torrid climates. A more simple illustration is that of immersing one hand in water at 40° F. and the other in water at 120° F., and then both in water at 80° F., when one hand will feel hot and the other cold, though both are subjected to the same temperature. Again, during a chill the temperature of the body is often very considerably elevated, and yet the sensation is entirely of cold.

Taste.

Taste—necessary conditions: Aside from the conditions which are always necessary for sense-perception—viz., proper organs for receiving, communicating, and perceiving the sensory impulse—there must be present a sapid substance which must be in solution. The solution in the case of dry substances is effected by the saliva. It is also necessary that the surface of the organs of taste shall be moist. The substances

which excite the special sensation of "taste" act by producing a change in the condition of the terminal filaments of the gustatory nerve, and this change furnishes to it the required stimulus.

Origin of taste: Chiefly from the *tongue*, though there is some power to taste resident in the soft palate, fauces, tonsils, and pharynx. In the tongue the taste is more acutely developed in the posterior portion, though in most the tip and sides are sensitive to taste. The central portion of the dorsum is not an actively sensitive taste-organ. The under surface of the tongue is little if at all sensitive to taste.

The nerve-supply for sense of taste is probably the glosso-pharyngeal. The lingual branch of the fifth (or "gustatory") is also a *conductor* of taste-impressions for the front of the tongue, but by means of the fibres from the chorda tympani and otic ganglion (see page 172).

The **tongue** is a flattened muscular organ covered by epithelium. It is controlled by intrinsic and extrinsic muscles, which give it a remarkable flexibility of movement; the latter for its larger, and the former for its more delicate actions.

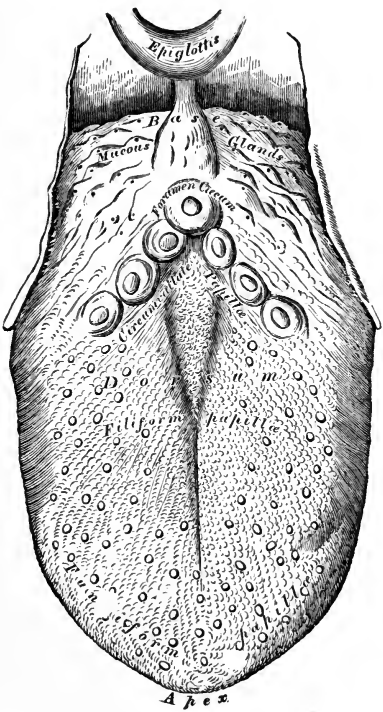
There are three varieties of papillæ found, which are known as *filiform*, *fungiform*, and *circumvallate* papillæ. These are set chiefly upon the dorsum of the tongue; and over its whole surface are numerous mucous follicles, whose secretions keep the tongue moist (Figs. 105, 106, and 107).

The *filiform papillæ* are set upon the middle of the dorsum, and are scattered over the entire surface, and are far more numerous than any other kind. They are conical in shape, and are covered with epithelium, which projects in a brush-like tuft from the apex. Their function is mostly tactile, and in animals, especially of the cat tribe, are very prominent.

The *fungiform papillæ* are chiefly distributed over the sides and tip of the organ, and sparsely upon the dorsum. They are larger at the surface than at the base, club-shaped, and are supplied with bloodvessels and nerves. Their function is probably sensory (Fig. 106).

The *circumvallate papillæ* are somewhat similar in shape to the fungiform, but considerably larger. They are situated at the posterior portion of the dorsum in a V-shaped arrangement, and number only eight or ten. Around the circum-

Fig. 105.



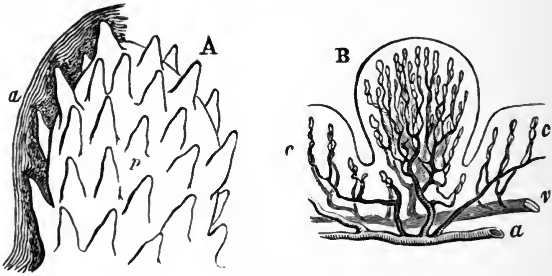
Upper surface of the tongue.

vallate papillæ are the *taste-goblets*, or gustatory buds, which are the form of nerve-ending characterizing the parts where this sense is developed (Fig. 107).

Other sensations in the tongue: The sense of *touch* is very highly developed here, and with it the sense of temperature, pressure, pain, etc.: upon these tactile and muscular senses to

a great extent depend the accuracy of the tongue in many of its important uses—speech, mastication, deglutition, sucking.

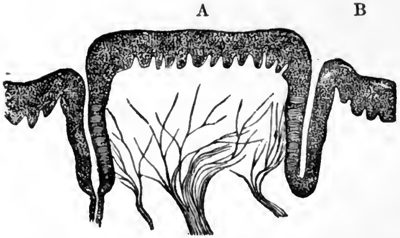
FIG. 106.



Surface and sectional view of a fungiform papilla. A, the surface of a fungiform papilla partially denuded of the epithelium (35 diameters): *p*, secondary papillæ; *a*, epithileum. B, section of a fungiform papilla with the bloodvessels injected: *a*, artery; *v*, vein; *c*, capillary loops of simple papillæ in the neighborhood, covered by epithelium (from Kölliker, after Todd and Bowman).

The tactile sense is very important, too, in the sense of taste, for with many substances the taste is largely due to their me-

FIG. 107.



Vertical section of a circumvallate papilla, from the calf (35 diameters). A, the papilla; B, the adjacent surface. The figure shows the nerves of the papilla spreading toward the surface and toward the taste-buds which are imbedded in the epithelium at the sides; in the sulcus on the left the duct of a gland is seen to open (Engelmann).

chanical condition: this is the case with mucilaginous, oily, and chalky tastes.

Association of smell and taste: It is important, for with many substances—particularly aromatic substances—of food

and drink the association of smell and taste is very essential to a thorough appreciation of a flavor. Most cooked foods lose their savor if the nose is obstructed; thus with a "cold" in the nose "everything tastes alike."

The principal *tastes* are sweet, bitter, acid, alkaline, and saline. Besides these, the general sensibility of the tongue detects pungent or caustic and styptic tastes, as well as the oily and mucilaginous tastes.

Sensibility of tongue: It is quite acute. A solution of acid or bitter substances is tasted when very dilute: strychnine is said to be tasted in a 1 : 600,000 solution; sulphuric acid, 1 : 1000.

After-taste: After an aromatic substance has been tasted there remains in the mouth an impression of that flavor; and if such substances be taken in rapid succession, the appreciation of their flavor is lost. This impression, which is left by a strong flavor, is called the after-taste, and is utilized sometimes to cover the taste of a disagreeable medicine, a strongly flavored aromatic preceding it.

Smell.

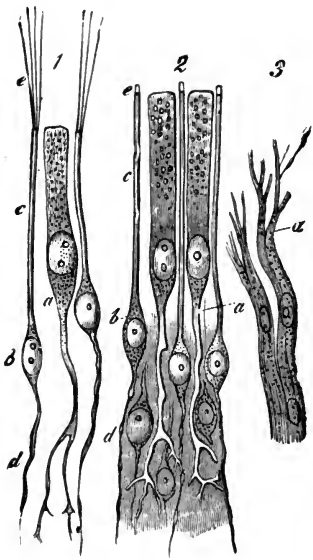
Smell—conditions: The first essentials are a special *nerve* and *nerve-centre*, the changes in whose condition are perceived as sensations of odor. No other nerve-structure is capable of such sensations, even when acted on by the same cause. The special organs for this sense for the reception, conduction, and perception of the stimulus, as in the case of any of the senses, must be in their normal condition, and a stimulus (an odor) must be present to excite them.

Odors are caused either by minute particles of solid matter or by gases which are in the atmosphere, and they must be capable of *solution* in the mucus of the Schneiderian membrane. The substance must pass in a current of air through the nostrils or it is not perceived as an odor. This is accomplished by "sniffing" the air, and thus creating an intermitting current which is tested by the olfactory sense. In this way a trace of a gas or impalpable powder may be detected which cannot be traced by chemical or other means.

If the substance be applied as a solution, it is not detected; thus, rose-water in a nasal douche is not noticed while the nostrils are full of fluid, and yet as soon as the nostrils are free the odor appears.

The **olfactory nerves** are the functional nerves of the sense, and are spread out in a fine network (Fig. 109) over the sur-

Fig. 108.



Cells and terminal nerve-fibres of the olfactory region, highly magnified. 1, from the frog; 2, from man: *a*, epithelial cell, extending deeply into a ramified process; *b*, olfactory cells; *c*, their peripheral rods; *e*, their extremities, seen in 1 to be prolonged into fine hairs; *d*, their central filaments; 3, olfactory nerve-fibres from the dog; *a*, the division into fine fibrillæ (Frey, after Schultze).

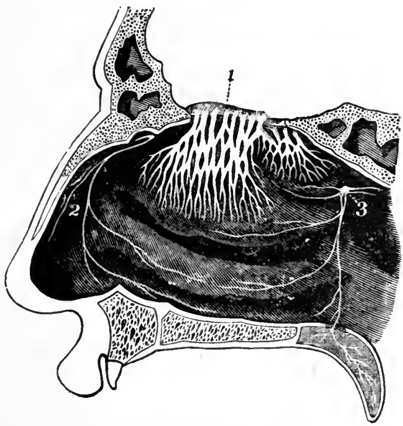
face of the superior turbinated bone and on the upper third of the septum. The nerves end in special end-organs, known as *olfactory cells* (Fig. 108), which lie under the ciliated epithelium of the part.

Origin of olfactory nerves: The nerves arise from a mass of gray matter lying beneath the anterior lobe of the brain upon

the cribriform plate of the ethmoid bone. This is the *olfactory bulb*, and it is connected by the *olfactory tract* with the cerebrum. Each olfactory tract arises from the cerebrum by three roots, two of which are composed of white matter, the other largely of gray matter. By these it is connected with the olfactory centres.

The lining membrane of the nasal cavity is very sensitive to irritation, the nasal branch of the fifth nerve and branches from the spheno-palatine ganglion furnishing the ordinary

Fig. 109.



Distribution of nerves in the nasal passages; 1, olfactory bulb, with its nerves; 2, nasal branch of the fifth pair; 3, spheno-palatine ganglion.

and tactile sense. Therefore we can perceive, by the nose, the sensations of cold, heat, itching, tickling, pain, and tension or pressure.

The perceptions of the olfactory and of the nerves of touch often resemble each other, and some stimuli affect both nerves. The common sensibility is evoked by such substances as are irritating and acrid: ammonia gas has no odor, but it stimulates the mucous membrane by its irritating properties. The tactile or common sensibilities remain when the olfactory are gone. The relation between the two kinds of perception is

lost to us, and we speak of the smell of ammonia or of alcohol when it is probably not an olfactory, but a sensory, perception.

Acuteness of smell: The sense of smell is very acute, but not so sharp in man as in many of the lower animals. The distribution of the olfactory nerves is much wider in some of the animals, and the cerebral development is correspondingly increased. In man the *range* of susceptibility is, however, probably greater. The variety of odors and the very minute quantity of stimulant substance required to produce a sensation of smell are quite wonderful. The most delicate analysis may fail to show traces of the substances which can be appreciated by the sense of smell. For instance 0.000000005 gramme of oil of peppermint in 1 litre of air can be appreciated.

There are some odors pleasant to some which others find almost intolerable. Musk, for example, is a pleasant perfume to some, while to others it is quite unendurable. In the same way, the acuteness of this sense in some is more marked than in others, and yet this may apply only to certain kinds of odors. Like the sense of touch and the other special senses, that of smell can be very much developed by practice. Large salaries are paid to experts in discrimination of the quality of wines, etc. Often in cases of mental disease there are hallucinations of smell, which also may occur in cases of disease of the olfactory centres, when there may be frequent complaint of a bad smell. With normal organs there may be a sensation of an odor which cannot be detected by others present.

Sneezing: The act of sneezing is a violent and sudden expulsion of air through the nasal passages. The act is a reflex one and the exciting cause is a stimulation of the nasal filaments of the fifth or trifacial nerve.

Hearing.

The **auditory apparatus** consists, in brief, of (1) the external ear; (2) the middle ear; (3) the internal ear; and (4) the auditory nerve.

External ear: The external ear consists of the *auricle* and *external auditory canal.* The former serves to receive the sound-waves and to indicate the direction from which they come in animals which possess the power of moving the organ. Through the external auditory canal the sound-waves are conducted to the middle ear.

The **middle ear**, or tympanum, is a cavity in the temporal bone which is shut off from the external auditory canal by the *membrana tympani.* The *Eustachian tube* connects this cavity with the pharynx. The lining of the middle ear is

Fig. 110.

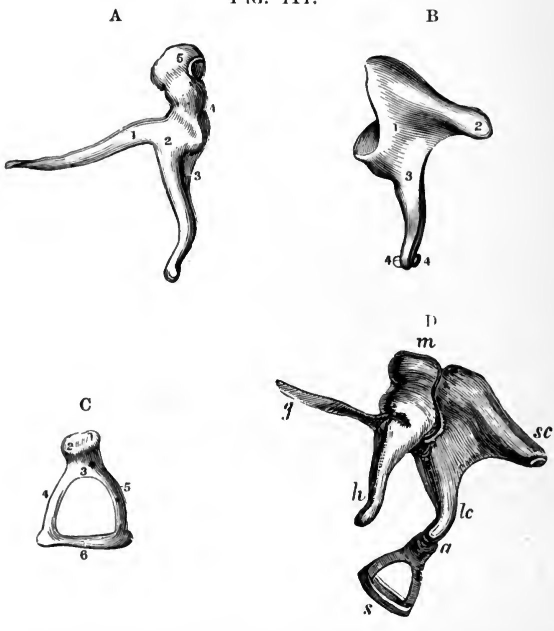
Right temporal bone of the new-born infant, seen from its inner side, showing the membrana tympani and chain of bones in their natural position (Rüdinger).

partly ciliated epithelium, continued from the mucous membrane of the pharynx through the Eustachian tube. There are two openings of importance—the fenestra rotunda and the fenestra ovalis—in the bony wall, but they are covered, the former by a membrane, the latter by the stapes. The middle ear also communicates posteriorly with the *mastoid-cells*, which are air-cavities in the mastoid process of the temporal bone. Its only communication with the external air, however, is through the Eustachian tube. There is a chain of small bones (ossicles) which connect the membrana tympani and the fenestra ovalis.

Membrana tympani: It is a tough, tense, fibrous membrane set in the bony opening of the external auditory canal. The degree of tension of the membrane is regulated by the tensor tympani muscle.

Ossicles: They are three in number (Fig. 111), and are so

FIG. 111.



Bones of the tympanum of the left side. A, malleus: 1, long or slender process; 2, near neck; 3, the handle; 4, short process; 5, head. B, incus: 1, body; 2, short or posterior process; 3, the long process with the orbicular process. C, stapes: 1 and 2, head; 3, neck; 4, 5, crura; 6, base. D, the three bones in their natural connection; *m*, malleus; *sc*, incus; *s*, stapes.

articulated as to communicate the vibration of the membrana tympani to the internal ear (Fig. 110). The handle of the *malleus* is attached to the membrane, so that this bone moves with each vibration. This motion is communicated to the *incus*, which passes it on to the *stapes*. The *stapes* rocks in the fenestra ovalis, and is therefore capable of transmitting to

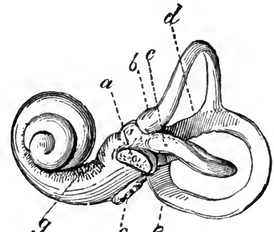
the fluid in the cavity of the labyrinth the impulses which it receives.

Eustachian tube: The Eustachian tube or canal leads from the cavity of the pharynx to that of the middle ear. It is completely pervious and allows a free passage of air from the pharynx to the middle ear.

Its chief purpose is to provide for the maintenance of an equal pressure on both sides of the membrana tympani, by keeping the air in the middle ear in communication with the outside air. It also serves to render sounds clearer (as the apertures in violins do), and as an outlet for mucus.

Internal ear: The proper organ of hearing is formed by the distribution of the auditory nerve within the *internal ear* or bony and membranous labyrinths. The bony labyrinth is situated in the dense petrous portion of the temporal bone, and consists of three essential parts: the *vestibule* (Fig. 112), and opening from it the *semicircular canals* and the *cochlea*. There is another opening, the aqueductus vestibuli, whose use is doubtful, and still others for the entrance of the auditory nerve-filaments. Within the bony labyrinth is the *membranous labyrinth*, a series of tubes and sacs composed of fibrous tissue, lined with epithelium, which contains a colorless fluid, the *endolymph*, while a fluid surrounds this membranous labyrinth, the *perilymph*.

Fig. 112.



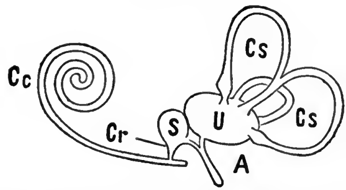
External view of a cast of the left labyrinth (Henle). *f*, fenestra rotunda, or round window; *a*, fenestra ovalis, or oval window; *b*, ampulla of superior semicircular canal; *c*, ampulla of horizontal semicircular canal; *d*, common shaft of union of these two canals; *e*, ampulla of posterior semicircular canal; *g*, promontory (the line should extend more to the right).

Semicircular canals: These canals are arched cylindrical spaces in the solid bone which open at each end of the arch into the vestibule. They are three in number, and two are nearly vertical and one is horizontal. These canals are arranged in such a manner that the planes of the two vertical canals are at right angles, one being antero-posterior, and the other transverse (Fig. 112). These canals have within them complete mem-

branous tubes, considerably smaller than themselves; so that the perilymph occupies the space between the bony wall and the membranous wall, while the endolymph occupies the cavity of the membranous semicircular canals (Fig. 113).

Within the cavity of the *membranous semicircular canals* are found the terminations of some filaments of the auditory nerve. These filaments end in collections of cells called "cristæ acusticæ." A similar collection of nerve-cells, called "macula acustica," is found in the membranous chamber

Fig. 113.



Membranous labyrinth. Cs, semicircular canals; U, utriculus; S, sacculus; A, aqueduct of vestibule; Cr, ductus reuniens; Co, cochlea.

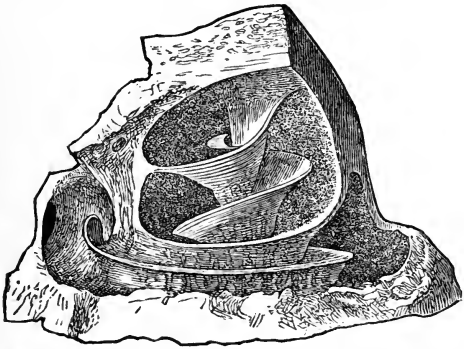
(utricle), situated in the vestibule, into which the membranous semicircular canals open.

The *use* of the semicircular canals does not seem to be directly connected with the auditory function of the part, but to be connected more with the sense of *equilibrium.* The movement of the fluids in the canals, arranged in the directions of the three dimensions, may serve to produce sensations upon the cristæ acusticæ which lead to the formation of accurate judgment of changes in the position of the body.

Cochlea: It is a part of the bony labyrinth which derives its name from its resemblance to a snail-shell. It is divided into two parts by a bony and membranous septum which runs parallel from base to apex of the spiral (Fig. 114). The "upper" passage opens out of the vestibule, and is known as the *scala vestibuli;* the "lower," the *scala tympani,* is shut off by a membrane, which covers the fenestra rotunda, from the cavity of the tympanum. The scala vestibuli is subdivided by a membrane, which passes from the bony *lamina spiralis* to the wall of the scala vestibuli, shutting off a tri-

angular space (canalis cochlearis). The floor of this space is the membranous partition (*membrana basilaris*) which sepa-

FIG. 114.



Bony cochlea of the human ear, right side, opened from its anterior face (Cruveilhier).

rates the scala tympani from it, and upon this membrane is the *organ of Corti.*

The *roof* of the triangular space is the *membrane of Reissner.*

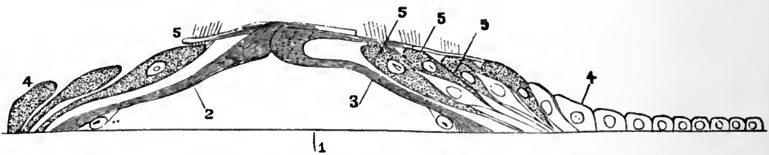
Canalis cochlearis: The canalis cochlearis, or *scala media*, is the representative of the membranous labyrinth occupying the bony cochlea. It is a single continuous tube, spiral in shape so as to conform to the shape of the bony cochlea. On cross-section it is seen to be triangular, or, more correctly speaking, the segment of a circle. Its apex lies just over the edge of the lamina spiralis, and its base against the circumference of the bony cochlea. Its upper side is the membrane of Reissner, and its lower side the basilar membrane.

At the apex of the spiral cochlea the canalis cochlearis terminates as a blind end. At the base of the cochlea the canalis cochlearis connects by means of a tiny duct (canalis reuniens) with a round membranous chamber (the *saccule*). The *saccule* and *utricle* are those portions of the membranous labyrinth occupying the bony *vestibule*. The saccule and utricle communicate with each other by means of the "ductus endolymphaticus," a minute tube lying in the aqueductus

vestibuli. Thus it is seen that the canalis cochlearis is filled with endolymph, freely communicating with the interior of the rest of the membranous labyrinth; but nowhere does the endolymph communicate with perilymph.

Organ of Corti: Upon the basilar membrane is arranged a series of rafter-like bodies which roof in a small canal (Fig. 115); upon this are spread the functional nerve-endings of the auditory nerve. These rafter-like bodies are large nucleated cells, the rods of Corti, having resting upon them other epithelial cells with hair-like processes which project into the canalis cochlearis or scala media. When looked at from above the cells have an appearance similar to the key-

Fig. 115.



Diagrammatic section of the organ of Corti. 1, membrana basilaris; 2, 3, internal and external rods of Corti; 4, epithelial cells near inner and outer borders; 5, hair-cells lying in contact with the rods (magnified 500 diameters).

board of a piano. Fibres of the auditory nerve spread to these cells from the bony lamina spiralis.

It is probable that each of the functional cells in the organ of Corti responds to a particular shade of sound.

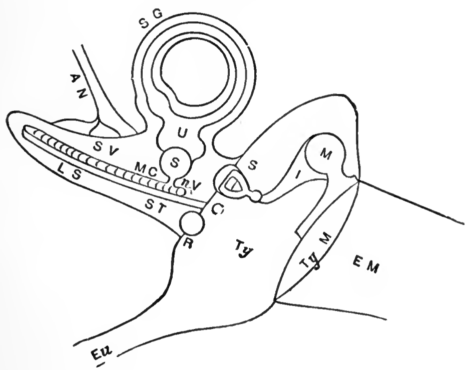
Auditory nerve: The VIIIth cranial or auditory nerve is purely centripetal in its functions. Anatomically we say that its fibres arise from a nucleus of gray matter in the floor of the fourth ventricle, and from this source pass out through the substance of the medulla in a number of small bundles which unite with another root which has connections with the *cerebellum* to form a trunk. This passes with the facial nerve into the internal auditory canal, and terminates in special end-organs in the internal ear.

Its fibres contain numerous ganglion-cells. In the cochlea there are many of these cells, and they form plexuses of nerve-fibres to supply the hair-cells. The absence of neuri-

lemma in the auditory nerve gives it a soft feel which has caused the name "portio mollis" to be given to it when it and the facial were considered as a single nerve.

Course of sound-waves: Sound-waves of the air are gathered by the concha, carried into the external auditory canal and vibrate against the membrana tympani. The membrane taking up the vibrations transmits them through the chain of ossicles to the stapes in the fenestra ovalis. The stapes imparts its motion to the perilymph of the vestibule

Fig. 116.



Diagrammatic view of the relative position of the parts of the ear. EM, external meatus; *Ty*M, tympanic membrane; T*y*, tympanum; M, malleus; I, incus; S, stapes; R, round window; O, oval window; SG, semicircular canal; U, utriculus; S, sacculus; V, vestibule; SV, scala vestibuli; *ST*, scala tympani; MC, membranous cochlea; LS, lamina ossea; E*u*, eustachian tube; AN, auditory nerve; *N*, canalis reuniens.

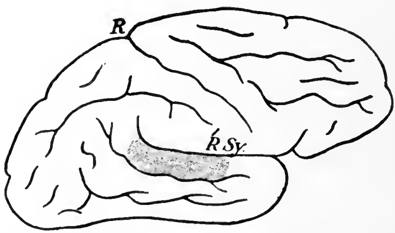
(Fig. 116). There is now set up in the perilymph a fluid-wave that travels in all directions. Some of this fluid-wave travels along the scala vestibuli to the apex of the cochlea, then through the aperture of communication with the scala tympani, then down the latter until it expends itself against the membrane in the fenestra rotunda. In its passage along the scala vestibuli and scala tympani, the fluid-wave vibrates against the membrane of Reissner and basilar membrane; and this sets up similar vibrations in the endolymph of

the canalis cochlearis. The fluid-wave in the canalis cochlearis irritates the hair-cells of the organ of Corti. These cells seem to be able to respond to particular tones by their sensitiveness in selecting each one its particular fluid-wave with its particular rate of vibration.

The remainder of the fluid-wave is expended in a similar manner through the vestibule and semicircular canals, with similar effects on the saccule, utricle, and membranous canals.

Localization of hearing: The branch of the eighth nerve, "arising" in the organ of Corti, having received its impulses from the organ of Corti cells, transmits its impulse to the

FIG. 117.



Position of the auditory centre in the first temporal convolution (Gowers).

centre under the acoustic tubercle in the floor of the fourth ventricle; thence fibres pass by means of the trapezium (in the pons) to the opposite side, and thence through the lower fillet of that side to the posterior quadrigeminal body, whence, by means of its brachium, internal geniculate body, optic thalamus, and internal capsule, they proceed to the cortex of the first and second temporal convolutions (Fig. 117).

Distance: We can only judge of the distance of the source of a sound by its intensity. The sound itself is in the ear. Ventriloquists take advantage of this fact, and, by modifying the intensity of the voice in imitation of the effect of distance, cause us to think that it really originates at a distance.

Subjective hearing: By this heading is meant those sounds

that are distinctly heard and yet are not produced by physical sound-waves, nor are they hallucinations. They may be due to disturbances of the auditory apparatus or to abnormal conditions of surrounding organs. Thus, buzzing or ringing in the ears may result from the hyperæmia of the parts and exaggerated rush of blood, or from a defect in the circulating apparatus (as by an aneurism), or from disease in the auditory nerve or some other portion of the apparatus. Hallucinations of hearing are very common among the insane, and are purely creations of the disordered brain.

Musical range of hearing: The range of musical notes that can be appreciated by the human ear is about seven octaves. There are about three thousand hair-cells in the organ of Corti, and it will be easily seen that this would allow an enormous capability to differentiate sounds and musical tones. This corresponds to a range of from 40 to about 4000 vibrations per second. The range of audibility, on the other hand, is about eleven octaves, or from 16 to 38,000 vibrations per second. With less than 16 vibrations per second we are conscious only of separate shocks, while with more than the larger number we are unconscious of sound altogether.

Voice or Speech.

Although the **voice** or speech cannot be called part of the senses, nevertheless it seems appropriate to describe its mechanism under the general subject of "The Senses."

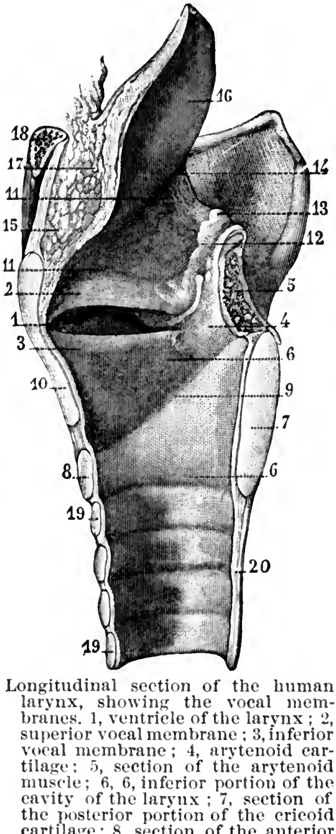
The larynx: The larynx is the organ of voice. It is a cavity closed laterally, but communicating with the trachea below and the pharynx above. The walls are made up of the thyroid, cricoid, and arytenoid cartilages, together with various muscles and membranes (Fig. 118). For a detailed description see Quain's or Gray's *Anatomy*.

Across the cavity of the chamber are stretched in an antero-posterior direction the two *vocal cords* or "membranes." The free passage between the vocal cords is the *glottis*, the cords forming part of the rima glottidis.

Production of voice: Voice is a result of the vibrations of the vocal cords. The vibration of the vocal cords is

produced by the passage of the air in expiration, never naturally in inspiration. The quality of the voice as regards pitch depends upon the length of the vocal cords, the crico-thyroid muscles acting to increase the tension, while the thyro-arytenoids relax the cords and the crico-arytenoids dilate and contract the rima glottidis. Falsetto and high-pitched notes in a naturally low-pitched voice are due to vibration at the edges of the cords. The hollow spaces about the oral and nasal cavities are of use as resonators or sounding-boards.

FIG. 118.



Longitudinal section of the human larynx, showing the vocal membranes. 1, ventricle of the larynx; 2, superior vocal membrane; 3, inferior vocal membrane; 4, arytenoid cartilage; 5, section of the arytenoid muscle; 6, 6, inferior portion of the cavity of the larynx; 7, section of the posterior portion of the cricoid cartilage; 8, section of the anterior portion of the cricoid cartilage: 9, superior border of the cricoid cartilage; 10, section of the thyroid cartilage: 11, 11, superior portion of the cavity of the larynx; 12, 13, arytenoid gland; 14, 16, epiglottis; 15, 17, adipose tissue; 18, section of the hyoid bone; 19, 19, 20, trachea.

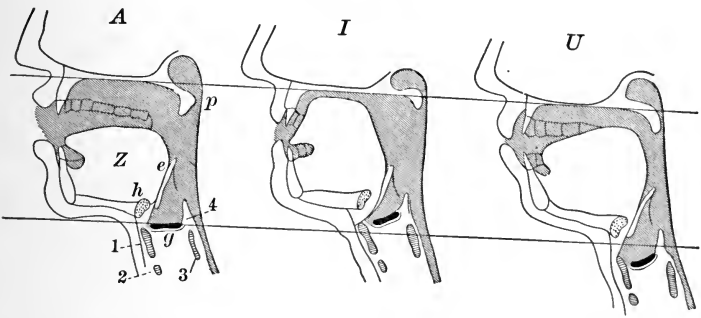
Articulate speech: The voice comes from the larynx; but articulate speech is the result of the modification of the voice by the tongue, etc. (Fig. 119).

The organs used in articulate speech are: The tongue and teeth in the formation of the linguals and dentals; the nasal sounds by the cavity of the nose; the other sounds are formed largely by modifications in the shape of the mouth in one or another part.

Musical range of the voice: The musical range of a human voice is from one to three octaves. In this, cultivation and natural aptitude are factors which permit great variability. The total range

of the human voice from the highest soprano to the lowest bass is about four octaves. Thus it will be seen that the

FIG. 119.



Section of the parts concerned in the formation of vowels. *Z*, tongue; *p*, soft palate; *e*, epiglottis; *g*, glottis; *h*, hyoid bone; 1, thyroid: 2, 3, cricoid; 4, arytenoid cartilage (Landois).

range of sounds which can be appreciated by the ear is far beyond the capacity of the voice.

Sight.

The **visual apparatus** is the eye with its accessory organs and the optic nerve.

The function of the eye is the reception of stimuli of light, whereby we are able to perceive the impressions of form, color, and conditions of our surroundings in infinite variety. It is far the most complex in structure of any of the organs of special sense, and the most rapid and delicate in its actions. The stimulus received by the eye is transmitted along the optic nerve to the brain.

Accessory organs of the eye: Under this heading we class the (1) eyelids, (2) lachrymal gland, (3) extrinsic muscles of the eyeball.

Eyelids: Each eye has two lids, an upper and a lower. Each consists of a thin plate of elastic tissue with a covering of loose skin and a smooth lining of mucous membrane—the conjunctiva—which is reflected upon the eyeball. Along the

edges of the lids are a number of short curved hairs which screen the eye from foreign bodies. The extreme sensitiveness of the conjunctiva helps in this by giving immediate warning when any foreign substance gets in the eye.

The *muscles* of the eyelids are the levator palpebræ superiores and the orbicularis palpebrarum.

Lachrymal gland: It is a small racemose gland lodged in the upper and outer part of the orbit. It has several ducts, which lead to the surface of the conjunctiva of the upper lid. The secretion of the gland is usually just sufficient to keep the eye moist, but under the stimulus of pain or intense emotion the secretion is increased, and appears in drops which flow from the eyes—*tears*. Under ordinary circumstances a slight excess of this moisture is drained into the nasal cavity by the lachrymal duct. This secretion is slightly alkaline, and contains about 1 per cent. of solids, chiefly sodium chloride.

Meibomian glands: They consist of a number of small racemose glands, lying beneath the conjunctiva, which secrete an oily protective substance. The ducts of these glands open along the edge of the lid.

Extrinsic muscles of the eye: There are six muscles to each eye—superior rectus, external rectus, inferior rectus, internal rectus—situated respectively above, below, and to the inner, and outer sides of the eyeball; also the superior oblique at the upper and inner angle of the orbit, and the inferior oblique at the lower and inner angle.

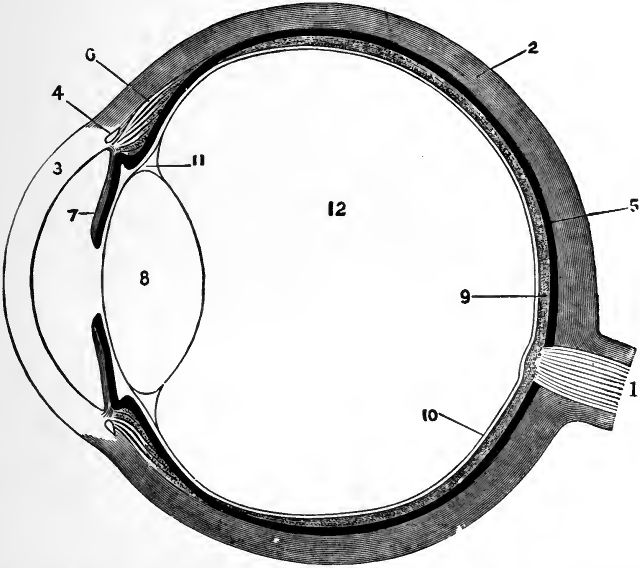
The *recti* serve to turn the eye up, down, in, or out, according to which muscles or combination of muscles are acting. The *oblique* muscles tend to rotate the eyeball on an antero-posterior axis.

The superior and inferior recti of both eyes work synchronously, but the action of the external rectus of one eye is synchronous with the internal rectus of the other; and the same is true as between the superior oblique of one eye and the inferior oblique of the other. The object of the action of all these muscles is to turn the eyeballs toward the object to be seen, thus causing it to receive the majority of the rays from the object at right angles to the surface of the eye. The superior oblique muscles are supplied by the fourth cranial

nerves; external recti by the sixth; the other muscles by the third cranial nerves.

The **eyeball** consists of a tough, opaque *globe* (Fig. 120), having a somewhat more sharply-curved translucent portion, the cornea, at the front. It has in the anterior portion a *lens*, and in front and behind this are chambers which contain

FIG. 120.



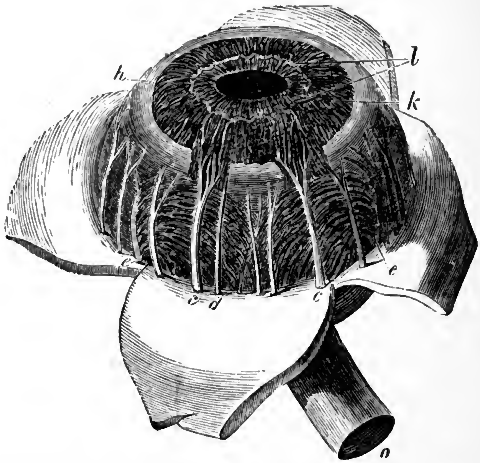
Horizontal section of the right eyeball. 1, optic nerve; 2, sclerotic coat; 3, cornea; 4, canal of Schlemm; 5, choroid coat; 6, ciliary muscle; 7, iris; 8, crystalline lens; 9, retina; 10, hyaloid membrane; 11, canal of Petit; 12, vitreous body.

fluids: the one in front is the *anterior chamber*, and contains the aqueous fluid, while in the posterior is the *vitreous humor*. These structures fill the eyeball and give it a tense feel to the touch.

Coats of the eyeball: The anterior portion of the eye, which has already been described as being more sharply curved than the rest, is the *cornea*. If we examine the rest of the eyeball (Fig. 121), it will be found to consist of three

coats: (1) The *sclera*, or *sclerotic coat*, is external, and covers about five-sixths of the globe. The cornea is continuous with it in front. It is composed of tough white fibres arranged in intercommunicating layers. (2) The *choroid* coat is very vascular, being composed of a mesh of capillaries. There is outside of this a layer of connective tissue containing pigment-

Fig. 121.



Choroid membrane and iris exposed by the removal of the sclerotic and cornea. Twice the natural size. *d*, one of the segments of the sclerotic thrown back; *l* and *k*, iris; *c*, ciliary nerves; *e*, one of the vasa vorticosa or choroidal veins (Quain). The ciliary muscle is crossed by the line from *k*, and should be represented as radiating.

granules, so that the choroid is black. (3) The *retina*, which is the seat of the end-organs of the optic nerve.

The purpose of the sclera is solely to act as a capsule for the contents of the eye. The choroid being black prevents any reflection of light. The retina is the nervous organ for receiving the sensations.

The **cornea** is continuous with the sclera in the front of the eye, and occupies about one-sixth of the surface (3, Fig. 120). Its shape is that of a small dome set upon the globe of the eye. It has in front several layers of epithelial cells, and at

the posterior surface a thin epithelial lining (membrane of Descemet); but the main body of the structure consists of interlacing connective-tissue fibres, which have spaces in which are found branching cells peculiar to the structure. The cornea is perfectly transparent; it has no bloodvessels.

The **aqueous humor** is a watery fluid contained in the anterior chamber. It acts with the cornea as a refracting medium to concentrate rays of light upon the lens, to maintain the globular form of the cornea, and to float the iris and allow it freedom of motion.

The indices of refraction for cornea and aqueous humor are about the same; so, as far as being media of refraction, we consider the cornea and aqueous humor as one, with an index of refraction of 1.33.

The **crystalline lens** is a double convex lens (8, Fig. 120) of high refractive power which is suspended in the anterior portion of the eye immediately behind the anterior chamber. Its function is to bring the rays of light to a focus upon the retina. In structure the lens is composed of concentric layers of long, slender fibres enclosed in a thin capsule. The index of refraction for the crystalline lens is about 1.45. The crystalline lens is suspended in its capsule by the suspensory ligament, and this is controlled by the ciliary muscle. At rest the eye is focussed for seeing at a distance, and the lens is held somewhat flattened by the tension of the suspensory ligament. When focussing upon a near object the ciliary muscle contracts, and the lens is permitted to project more as the tension of the ligament relaxes.

The **ciliary muscle** extends as a narrow zone of muscle-fibres near the anterior part of the choroid. The muscle-fibres originate at about the junction of the cornea and sclera and pass backward meridianally to be inserted in the choroid coat. On contraction the ciliary muscles draw the choroid coat forward; this relaxes the suspensory ligament of the lens and the lens becomes more convex.

When the ciliary muscle relaxes the reverse takes place, the choroid being replaced by the natural tension of the contents of the eye. The nerves to the ciliary muscle are from the ciliary ganglion.

The **iris** is a curtain of muscular tissue placed vertically in front of the lens. The fibres of the muscular tissue are both circular and radiating, so that they serve to decrease and increase the size of the pupil as one or the other set of fibres acts. It has a pigment-layer upon the inner surface, which is continued from the choroid, and upon the amount of the coloring-matter depends the "color of the eyes."

In the centre of the iris is a circular opening, through which light enters the "dark-chamber" of the eye. This opening is the pupil.

Nervous control of the iris: Contraction or dilatation of the pupil is a reflex act, and the afferent stimulus is carried through the optic nerve and the motor through the third cranial nerve, acting from a centre just beneath the aqueduct of Sylvius and the corpora quadrigemina. The increase in the amount of light which reaches the retina causes a contraction of the pupil, and a decrease is followed by dilatation. Aside from this, the needs of the eye regulate the amount of light; thus, for near work the pupil contracts, and dilates when the eye is focussed upon a distant object.

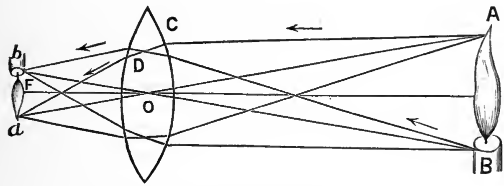
The pupil is controlled also through the sympathetic and the fifth nerve, through the connection of the third and fifth nerves with the ciliary ganglion of the sympathetic system. Drugs are active also, both locally and internally, in controlling the action of the iris without reference to the reflex fibres: atropine both locally and internally dilates the pupil; opium internally, and eserine locally contract it.

Vitreous humor: The vitreous body (or humor) is a semifluid gelatinous substance which fills the posterior chamber and constitutes about four-fifths of the bulk of the eye. It is quite transparent, and acts to maintain the tension of the eyeball, and as a refracting medium through which light reaches the retina.

Refraction: In order clearly to understand the nature of the image received by the eye, it will be wise to review the images cast by a convex lens. If we take, for example, a double convex lens and note the image formed by a luminous object, we see that it is an inverted image at the point of focus of the lens if the luminous object is placed at a distance (Fig.

122). Referring to this figure, it will be seen that the rays originating at A will be twice refracted, once by the lens and again in leaving it, so that all rays from A reaching the lens are joined at *a*. The same is true for B and *b*. Therefore a

FIG. 122.



Formation of image by convex lens.

screen placed at the focus, F, will receive an inverted image, *a b*, of the luminous object, A B.

If the lens were more convex, the image would be formed nearer the lens; if the lens were flatter, the image would be further from the lens.

Again, on the other hand, if we decide to have the image formed at a definite spot, the further the object is from the lens the flatter the lens must be, and *vice versa*, the nearer the object the more curved the lens must be.

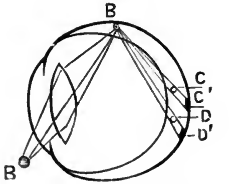
Thus, with a double convex lens we see that the image formed is a real, inverted image on the opposite side of the lens from the object.

Refraction in the eye: The crystalline lens is a double convex lens and so obeys the laws referred to in the previous paragraph.

In addition to the crystalline lens the other refracting media (Fig. 123) of the eye are the cornea, aqueous and vitreous humors. The tendency of all these refracting media is to bring together to one focus all divergent rays of light; thus they may be considered as a group of double convex lenses. The crystalline lens, however, is the most important, as it possesses the power, by virtue of the ciliary muscles, of increasing or diminishing its curvature.

Accommodation: By accommodation we mean the power of the crystalline lens to change its amount of curvature so as to throw the image of an object in exact focus on a fixed screen (the retina) whether the object be near or far from the lens. At the same time the pupil is expanded or contracted to admit the necessary amount of light. Thus, if an object be near the eye, in order to produce a sharp image the lens is more curved, owing to contraction of the ciliary muscle, and the pupil is contracted. If, on the other hand, the object be on the horizon, the ciliary muscle relaxes, the lens is flatter, and the pupil is dilated.

Fig. 123.



B, a candle placed at the side of the eye—that is, as much to the side of the centre of the cornea as possible. B′, interior luminous source, formed by the rays of light concentrated by the crystalline lens upon the extreme lateral portion of the eye. CD, two vessels of the retina (the size of the retina is here greatly exaggerated). The shadow of these two vessels is seen as if projected at D′ and C′. Experiment by Purkinje.

Comparison of eye to photographic camera: The eye may be compared to the photographic camera. It contains various media for the refraction of light, and a screen at the back for receiving the image. The refracting media are the cornea, aqueous humor, crystalline lens, and the vitreous humor: the screen is the retina. The pigment of the retina and choroid makes the interior dark, a necessary feature in such an apparatus. The mechanism of the lens enables the eye to be focussed for distance, while the iris regulates the proper admission of light.

In a camera the ground-glass screen, or the sensitive plate, is moved nearer or further from the back of the lens in order to bring it in focus—*i. e.*, make the image clear. In the eye the sensitive plate (the retina) is at a fixed distance from the lens, and so the focussing is done by a change in the curvature of the lens (accommodation).

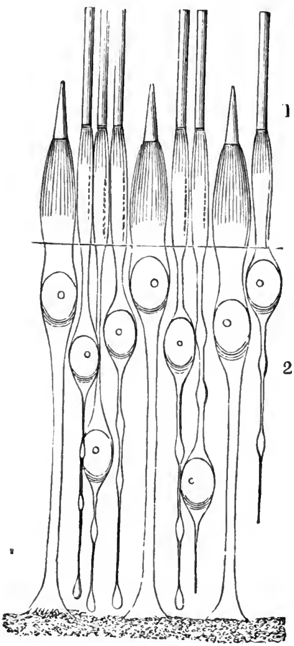
The **retina** is comparable to the photographic sensitive plate. It receives the images formed upon it by the lens and transmits the impressions to the optic nerve, whence they are carried to the brain.

It will be remembered that the retina forms the most central of the layers of the eyeball, but does not extend as far forward as do the choroid and sclera, but terminates at about half way.

The *fibres of the optic nerve,* after piercing the sclera and choroid at the back of the eye, spread out divested of neurilemma and medullary sheath into the *innermost* layer of the retina. The fibres then pass, with more or less direct communications, *peripherally* through the other layers until they may be said to terminate in the layers of rods and cones, external to which is a pigment-layer.

Rods and cones: They are closely packed on the outer surface of the retina, the rods being the more numerous in most situations. The cones seem to be modifications of the rods, and their office is essentially similar. The *rods* (Fig. 124) are straight cylindrical bodies of a transparent substance, and are placed parallel to one another and perpendicular to the surface of the eyeball. In length they are about five to seven times the diameter of a red blood-corpuscle, and in diameter about one-twentieth of their length. The *cones* are very similar, except that their conical shape makes them appear to be of different character. The cones do not always reach to the same level as the rods. When viewed from the *peripheral* surface the ends of the rods and cones give the appearance of a fine mosaic. These organs are connected with the subjacent layers, and, ultimately, more or

Fig. 124.



Diagrammatic section from the posterior portion of the human retina. 1, layer of rods and cones; 2, layer of nuclei (Schultze).

less directly, with the axis-cylinders of the fibres of the optic nerve.

The optic nerve pierces the eyeball not exactly at its most posterior point, but a little to the inner side. At the exact centre of the retina—that is, the most posterior point of the eye—there is a small yellow area (*macula lutea*) with a central depression (*fovea centralis*). Here are found none of the fibres of the optic nerve, but a great increase in the numbers of the *cones*, as well as an increase in their size.

Area of most acute vision: If the object looked at is focussed directly upon the *macula lutea*, the image is then seen with the greatest clearness. This is to be expected, for in the macula lutea we find the end-organs of the optic nerve most highly developed. In every-day life we look directly at an object so as to receive the image on the macula lutea and thus render the perception more acute. Rays of light entering the eye on an angle are focussed on some other part of the retina and are not so clearly defined.

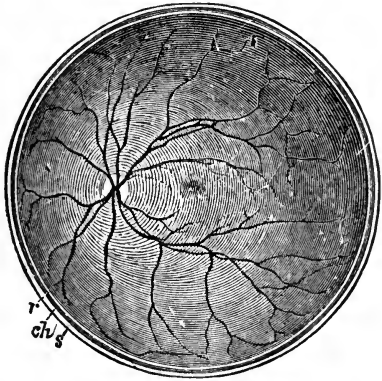
Blind spot: If the left eye is covered and the right directed steadily upon the cross in Fig. 125, the circular spot will be

Fig. 125.

visible at the same time, though less distinctly. As the book is moved slowly backward and forward, a point will be found at which the round spot disappears, reappearing as the book is held nearer or farther or as it is inclined in either direction and the image is carried away from the "blind spot."

The blind spot is the point where the optic nerve enters the eye. If the image be focussed on this point no perception follows, as that part of the retina is deficient in rods and cones (Fig. 126).

FIG. 126.



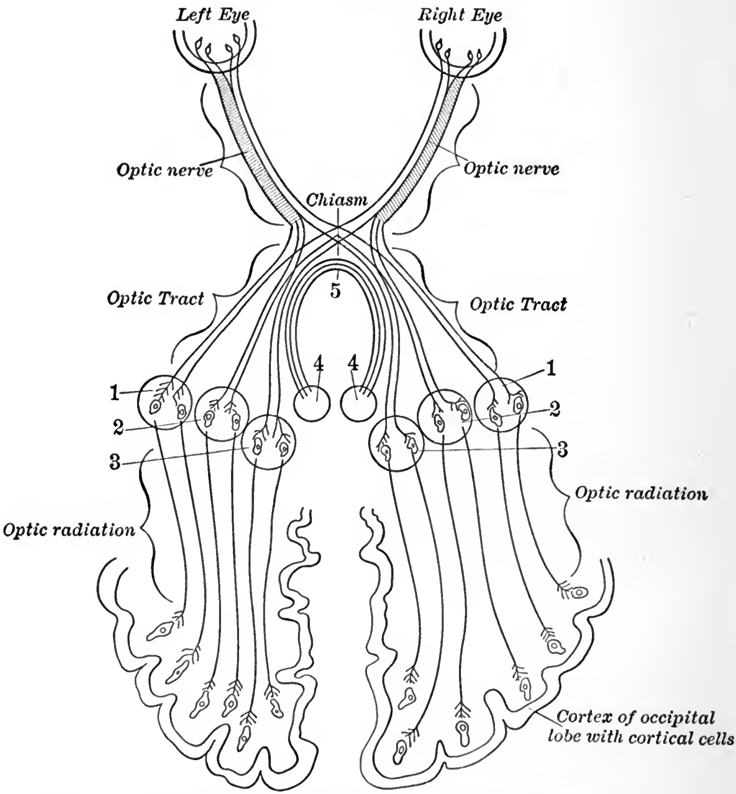
The posterior half of the retina of the left eye viewed from before. Twice its natural size. *s*, cut edge of the sclerotic; *ch*, choroid; *r*, retina: in the interior at the middle the macula lutea with the depression of the fovea centralis is represented by a slight oval shade: toward the left side the light spot indicates the colliculus or eminence at the entrance of the optic nerve, from the centre of which the arteria centralis is seen sending its branches into the retina, leaving the part occupied by the macula entirely free (Henle).

Optic nerve: If one examines the optic nerves in a superficial manner, they will be seen to leave the back of each eye, passing backward through the optic foramina until they reach the body of the sphenoids. Here the optic nerves cross one another in the form of an X (the *optic chiasm*), the fibres intermingling, and the right nerve apparently passing over to the left side and the left nerve to the right side. The posterior limbs of the X pass backward and are called the *optic tracts*. The **optic tracts** in their backward course curve around the crura cerebri to terminate in the ganglion-cells of the pulvinar, anterior quadrigemina, and external geniculate bodies. From the ganglion-cells of the pulvinar, anterior quadrigemina and external geniculate bodies, fibres, called the *optic radiations*, pass backward to terminate in the ganglion-cells of the cortex of the posterior part of the occipital lobes.

Fibres of nerves and tracts: A more minute examination of the optic nerves will show that each optic nerve consists of two distinct bundles of fibres laterally placed. The *inner*

set of fibres being the fibres from the inner half of the retina; the *outer bundle* of fibres coming from the outer half of the retina. If we trace these bundles backward to the optic

FIG. 127.



1, external geniculate body; 2, pulvinar; 3, anterior quadrigeminate body; 4, internal geniculate body; 5, commissure of Gudden.

chiasm, it is noted that only the inner bundles decussate and pass to the opposite side of the brain. The external bundles do not decussate, but pass directly backward as part

of the optic tracts to terminate in the ganglia on their respective sides of the brain.

Thus the left pulvinar, left anterior quadrigeminate and external geniculate bodies receive the fibres from the inner half of the right eye and the outer half of the left eye. The right ganglia receive fibres from the inner half of the left eye and outer half of the right eye.

Commissure of Gudden: There is also in the optic tracts a bundle of fibres arising from the *internal* geniculate body of one side, passing forward, as a third and innermost bundle of the optic tracts, to the back part of the optic chiasm; here the fibres bend on themselves and pass backward along the inner margin of the opposite optic tract to terminate in the other internal geniculate body. These commissural fibres form the *commissure of Gudden*, and serve to connect the two internal geniculate bodies. They play no part in vision.

Nervous mechanism of vision: The image, properly received on the retina, stirs the rods and cones into functional activity. The "vibrations" are then passed along the optic nerves and optic tracts to terminate in the pulvinares, external geniculate and anterior quadrigeminate bodies. These structures may be called the *primary vision centres*. Here the impressions of sight are received in a *physical* sense, but the *mind* does not as yet appreciate the sight impression.

The impression received by the ganglia are now transmitted along the optic radiations to the cortical cells of the occipital lobes. When the cortical cells are stimulated the mind is capable of appreciating that "*we see.*" So we may call the ganglia the seat of physical sight, but the cortical cells are the seat of physiological sight.

Binocular vision: In normal vision both eyes are used, so that a separate image is received on each retina. Through the intimate association of the two halves of the brain we are conscious of but one image.

A further advantage of binocular vision is that each eye looking at an object from a slightly different standpoint sees a little more on one side or other of the object than does the other eye. Thus the combined image formed contains a little more of the object than would the image from one eye alone.

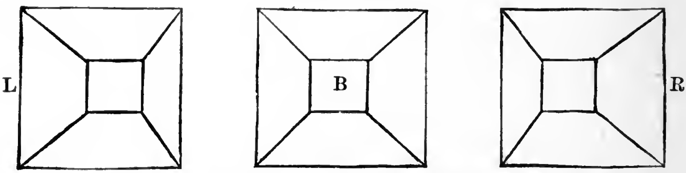
Thus the perceptive faculties can judge more correctly of the *form* and *distance* of an object.

The **stereoscope** illustrates this point. In this instrument two photographs are taken by cameras so placed as to represent the position of the eyes in vision, and the two views of one object are then superimposed by the use of prisms (Fig. 128).

Photographic views seen through a stereoscope possess a rounded-out, lifelike appearance not seen in ordinary photographs.

Inversion of the image: From the laws of optics we know that the image formed on the retina is an *inverted* image of

FIG. 128.



Illustrating the principle of the stereoscope and binocular vision.

the object. Yet we perceive the object in its upright position. This is the result of *lifelong habit.* A baby sees an object; the next step is to touch it; by practice the child finds out which is the top of the object through the touch-perception. He then corrects his mental impression. Very speedily the brain learns to make the correction, and the lesson once learned lasts through life.

The correction is made by the brain in its *perception* of the image. It is an act of mental and not of physical origin. Thus, objects which are projected upon the left of the retinal surface *look* to be, as they are, on the right of the body; and so with all the directions: the inversion of the retinal image is corrected by the mind.

Duration of visual sensations: The duration of a visual sensation is always greater than that of the stimulus which has caused it. However brief the luminous impression, the effect on the retina lasts about one-eighth of a second. The spokes

of a rapidly revolving wheel for this reason do no not appear as spokes, but as a solid mass, each following one another so rapidly that one impression cannot fade away before another has replaced it.

Mental processes acting on visual perceptions: We are able to estimate by the aid of the brain the size, direction, distance, form, and speed of motion of a thing which we have seen. All of these are judgments based largely upon previous experience. All of these deductions are liable to error by reason of faulty judgment or faulty vision, but this is the usual method of forming such estimates. As an example of visual illusion, the two centre squares shown in Fig. 129 are exactly the same size, yet the white square on the black ground appears larger than the black square on the white ground. Also in Fig. 130, the heavy black lines appear to converge, though in reality they are parallel.

FIG. 129.

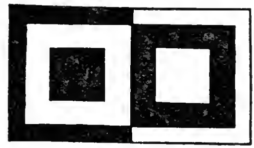


Illustration of irradiation (McKendrick).

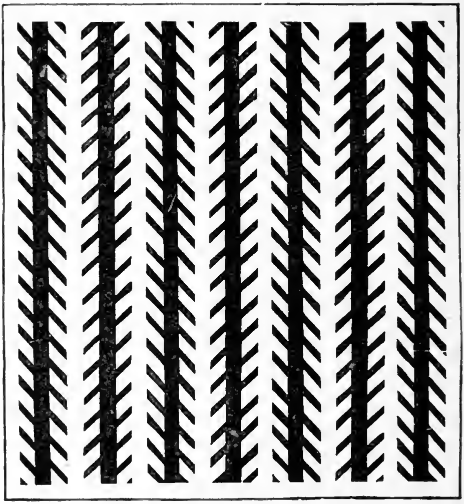
Clearness of vision depends on the space between the cones in the point of clearest vision, the macula lutea. It has been calculated that an object must subtend an arc of at least 60 to 70 seconds in the field of vision to be clearly seen. Such an object makes an image of about $\frac{1}{12000}$th of an inch in the retina; and this is about the distance between the cones at the macula lutea. Similarly, two points to be clearly distinguished must be separated sufficiently to allow this amount of separation in the retinal image.

Retinal red: When the retina of a recently-killed animal is examined it is colorless; but during life or if extracted without exposure to light, it is of a purple-red hue, and the color is found in the rods of the retina. It is derived from the pigment of the outer layer of the retina. It is the "retinal red" or "visual purple," as it is variously named, which one sees in the *reflex* of the retina.

Exposure to light destroys it, and for this reason it was long unknown. It disappears after a brief exposure to sunlight, about half a minute.

By throwing a beam of light into the eye by a mirror, as by the ophthalmoscope, a red glow is observed in the pupil.

FIG. 130.



Zöllner's figure showing an illusion of direction (McKendrick).

This is called the *retinal reflex.* The red glow is produced by the retinal red.

Optograms are pictures which appear upon the retina after exposure to light. They are due to the fact that an exposure to light bleaches the retinal red, leaving it dark in the shaded portions.

An optogram may be obtained by the following experiment: The eye is removed from an animal in a dark room and kept in a covered box until exposed to a brightly illuminated skylight or window for some minutes. The eye is then replaced in the dark room and the retina examined. It will be found that the panes of the window are shown in light color, while the sash is in dark outline. This soon fades on exposure to daylight; but if the retina is dried in the dark, the optogram is much more durable.

Pigment of choroid and retina: The student must not confound the "visual purple" with the pigment granules of the choroid and retina. The latter are dark brown or black, and serve to keep the chamber of the eye as a dark box. The black cloth of the photographer serves the same purpose. All optical instruments are painted black on the inside to prevent undesired reflection of light. So with the eye.

Color-perception: It is probable that particular rods and cones are capable of responding to rays of light of a certain wave-length, and to those rays alone. It is well known that the rays of red light are of a certain length of vibration. The same is true of yellow and of green rays. We can conceive that each primary color has its own set of cones and rods capable of responding to its stimulus, and that by combinations of these stimuli the complementary colors and variations of shade may be perceived by the resulting stimuli acting upon the brain-centres. Such teaching is, of course, speculative, but this is one theory which has acceptance.

Achromatism: If in obtaining an image of an object through a double convex lens the lens be too large, there will be seen around the image formed a halo of prismatic colors. This is called a chromatic ring, and is produced by an unequal refraction of light-rays by the peripheral portions of the lens. The unequal refraction results in a dispersion of the light, so that it is broken up into the seven primary colors. To remedy this defect, we put a "photographic shutter" in front of the lens, thus limiting the entrance of light to the central portions of the lens, where the index of refraction is "constant" or "true." In the eye the iris acts as the photographic shutter, thus rendering the image achromatic. It may, however, be said that there may be a visible band of color seen by some defective eyes where there is considerable fault in the focus of the image on the retina.

After-images: It has already been noted that vision lasts longer than the stimulus which excites it. Under some conditions it may last a perceptibly long time: it is then known as an *after-image*. If one looks at an intense light, the sun, the sense of light remains for some time in the eye. Similarly, if one looks intently at a white spot on a black background,

and then turns to a white surface, one has the image of a gray spot. The first of these conditions cited is known as a positive after-image, and the latter as a negative. In the first case the phenomenon results as a continuation of the same sensation, and in the latter a new perception results.

These images appear to have the complementary color of the original object; thus, green excites a reddish after-image; orange, blue; and so on. They may be explained as a result of exhaustion. The part of the retina on which the image has fallen becomes tired, and when the eye is turned upon a white ground, the white light coming to the retina does not produce as much sensation in the tired portion. The colored negative after-images may be similarly explained.

Near-point: The "near-point" is the nearest point to the eye at which vision is distinct, the shortest focus of the crystalline lens. It is usually about five or six inches.

Defective eyes: Although hardly within the scope of physiology, it may be perfectly appropriate to discuss here some of the more common defects of the eyes depending on abnormal conditions in the optical apparatus.

Emmetropic eye: It is the normal eye—that is, an eye in which parallel rays or rays from objects at a distance are focussed upon the retina without an effort at accommodation. Such a distance, for practical purposes, is considered to be any point beyond twenty feet. Absolutely emmetropic eyes are not common.

Myopia or "near sight" is the term applied to an eye in which the rays from a distance are focussed in front of the retina, and the image is blurred. Such an eye is permanently focussed for near objects (Fig. 132).

Myopia is produced in two ways—by the antero-posterior diameter of the eye being too great, or by the convexity of the lens being exaggerated. In either case the focus of the lens will fall in front of the retina.

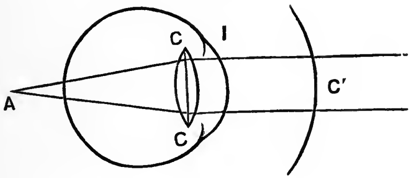
The first condition is essentially a congenital defect, whereas too great convexity of the lens may be either congenital or the result of disease.

Myopia is corrected by the use of a concave lens which diverges the rays, and in this way prevents their coming to a

focus too soon. Such glasses are seldom needed except for distant vision.

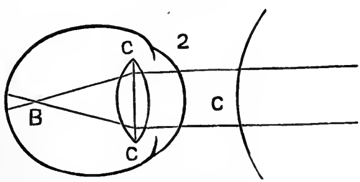
Hypermetropia, or "far sight," is the reverse of myopia (Fig. 131). In hypermetropia the antero-posterior axis of

Fig. 131.



the eye is too short, or else there is an abnormal flattening of the lens, which does not allow accommodation for near vision. The result is that the image of an object near by is focussed *behind* the retina; but objects at a distance are clearly seen.

Fig. 132.



Hypermetropic eye and myopic eye (far-sighted and near-sighted eye). 1, hypermetropic eye. The luminous rays arriving from an infinite distance (parallels) produce an ocular cone, the summit of which falls beyond the retina (at A), either because the cone is too long (lack of converging power in the media of the eye), or because the retina is too far forward (the eye being too short); 2, myopic eye; the luminous rays from an infinite distance (parallels) produce an ocular cone, the summit of which falls in front of the retina (at B), either because this cone is too short (excess of converging power in the media), or because the retina is placed too far back (the eye being too long). Donder's researches seem to show that short-sightedness is owing to this latter cause, as is well shown in the figure (the ocular globe being greatly elongated from back to front) (Kuss).

Hypermetropia is corrected by the use of convex lenses, which add to the refractive power of the eye.

Presbyopia is defective vision due to the loss of power in advanced years. The elasticity of the lens becomes less, and the convexity cannot be increased for near vision. The

ciliary muscle may also be weaker and aid in the production of the error. A weak convex glass commonly corrects the lack of refraction-power.

Thus we see that presbyopia is identical with hypermetropia due to flattening of the lens.

Astigmatism is a defect in the vision due to the irregularity in the globe of the eye, whereby the diameter in one plane is greater than in another. Thus, the retina may be an uneven surface, and the image focus accurately in one part and falsely in another. In this condition vertical and horizontal lines are not seen with equal distinctness.

Astigmatism is corrected by the use of cylindrical or prismatic glasses, which have to be accurately adapted to the needs of each case. This error, if serious, is usually combined with other defects of vision, frequently myopia.

Diplopia is the condition which results from a want of harmony in the eyes, so that the image of each eye is perceived separately; that is, one sees double.

Diplopia is commonly caused by paralysis or spasm in one of the lateral straight muscles, which does not allow the eye to be turned in harmony with the other. If the eyes are turned so that the axes of vision are separated, the condition is known as *external strabismus* or squint; if the axes are crossed, it is called *internal strabismus* or cross-eye.

Color-blindness is an inability to perceive some colors. The colors which are usually mistaken are green and red. Frequently it is found that a distinction cannot be made between these colors. This is sometimes known as Daltonism.

Theories of normal color-perception: Ordinary white light if decomposed is resolved into the seven primary colors—violet, indigo, blue, green, yellow, orange, and red. Each of these primary colors has a different wave-length. Other colors than the seven primary colors are the result of the mixture of two or more of the primary colors in various proportions. We are ignorant of the manner in which the rods and cones are made to vibrate by ordinary images, and we are equally ignorant as to the nature of the process that allows the different color-effects to be conveyed to the optic nerve.

As it is impossible to go fully into the matter in this book, it is hoped that the following will suffice:

The different color theories assume that there are different substances in the retina capable of responding to different wave-lengths of light (comparable to a photo-chemical process).

Red, green, and violet (Fig. 133) are the fundamental

FIG. 133.

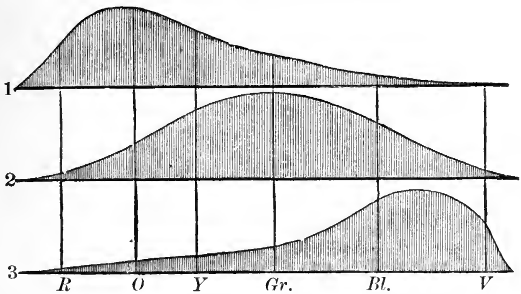


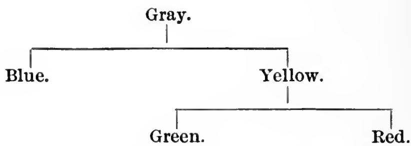
Diagram of three primary color-sensations. 1 is the so-called "red," 2 "green," and 3 "violet" primary color sensation; *R*, *O*, *Y*, etc., represents the red, orange, yellow, etc., color of the spectrum, and the diagram shows, by the height of the curve in each case, to what extent the several primary color-sensations are respectively excited by vibrations of different wave-lengths (Foster).

colors, and all others may be made from combinations of these three.

Working on this basis, Young and Helmholtz assumed three chemical substances in the retina capable of replying to the three fundamental colors.

Hering assumed three substances responding respectively to white or "black" (absence of light), red or green, and yellow or blue light. In this theory the white, red, and yellow rays are katabolic in their effect on their individual recipient substances; the "black," green, and blue being anabolic—*e. g.*, the substance responding to white is "broken down" by white light, but is regenerated ("built up") by "black light"—*i. e.*, absence of light. Mrs. Franklin assumes in her theory that in early life the eye possesses no color-perception, but merely perception of luminosity—*i. e.*, white or

black. The substance responding to luminosity she calls "gray-perceiving." As the development progresses, some of the "gray" is differentiated into a blue- and a yellow-perceiving substance. The yellow-perceiving substance is still further differentiated in the course of development into a red- and a green-perceiving substance; thus:



Many objections have been raised against each of these three color-theories, and it is true that each leaves some points unexplained; but Mrs. Franklin's is, so far, the best, and more readily explains the peculiarities of color-blindness.

Causes of color-blindness: The followers of Helmholtz and Hering say that color-blindness is due to an absence of one or more of the fundamental color-perceiving substances.

Mrs. Franklin's theory assumes a lack of full development or complete absence of development of the "gray"-perceiving substance.

Thus, in a case of absolute color-blindness the "gray" substance has undergone no development, and the individual sees everything as without color, but in different shadings of light or darkness. To such a person a highly colored painting would look like a black-and-white etching.

Again, working on the development theory, we may assume that the gray differentiated into "blue"- and "yellow"-perceiving substances and there stopped. Clinically we find individuals capable of distinguishing blues and yellows, but reds and greens are unknown to them.

Color-blindness in different sexes: Males are far more liable to be color-blind than female (16 to 1). Only about one woman in four hundred is color-blind. The reason for the preponderance of color-blind men may be accounted for on the theory that although the differentiation of the "gray"-perceiving substance into red, green, and blue is a natural

process, nevertheless it can be perfected by practice and color-education. Such an education is given early in life to little girls in matching colors for doll's clothing, etc., whereas, it is neglected in boys.

Importance of the defect: In marine and land locomotion, red and green signals are used to indicate opposite conditions, and the failure to distinguish them has frequently been the cause of serious accidents.

Test for color-blindness: By laying a number of skeins of yarn of various colors in a heap, and requiring the person to be tested to select all resembling a certain skein from the heap.

EMBRYOLOGY.

Embryology deals with the *reproduction* and *development* of individuals, whether of animal or plant life. We shall first study how the parent gives origin to the offspring, and later on the development of that offspring until it becomes a fully developed member of its species.

REPRODUCTION.

By **species** we mean a class of organized beings in which the individuals composing it die off, but which nevertheless repeats itself and maintains its complement by the continued accession of similar forms.

Heredity is the inherent property of the individual by virtue of which the individual is of the same species as the parent, and furthermore has certain individual characteristics of the parent. We are human beings because our parents were human beings, and we inherit the form and characteristics of the species. Still further, we may have certain tricks of speech, a peculiar gait or method of thinking, inherited from our individual parents.

Reproduction is the process by which a species is perpetuated, notwithstanding the limited existence of the individual members.

The law governing reproduction is that the young are of the same kind as their parents. By this law, which is so commonly observed as to seem a truism, is maintained the anatomical identity of individuals of a species, as well as the physiological fact of an unbroken continuance of the species by reproduction.

Methods of reproduction: Reproduction takes place by one

of two entirely distinct methods—asexual reproduction and sexual reproduction.

Asexual reproduction is the usual method among plants and animals whose organism consists of but one cell. It is also the method in some of the lower multicellular animals and many higher forms of plants.

When considering the *amœba* it was stated that it subdivided, with the result that from the single cell we had two distinct units, each being members of the same species. No sexual relations have taken place, and the offspring is the child of but one parent.

Sexual reproduction: Sexual reproduction consists of the union of elements produced separately by the female and the male. In some of the lower organisms there is no direct output from the male and female, but the two parents fuse together, and the resultant mass develops into the offspring; such a method is called "conjugation."

As we rise in the animal scale we find that the female produces the *ovum*, or egg, which is capable of being developed into a living offspring only when it is fecundated or impregnated by the *seminal* or spermatic element from the male.

In some animals (worms) both the male and female elements exist in the same individual; but still the offspring is the result of "sexual reproduction," although there is but one parent.

Theory of reproduction: Just why a cell should subdivide into two secondary cells, or why there should be the necessity for sexual reproduction, is a difficult problem to answer.

Asexual generation may be explained according to certain principles laid down by Herbert Spencer. Spencer pointed out conclusively that the mass of a cell grows as the cube, whereas the surface grows only as the square; from this it follows that the mass to be nourished soon outgrows the absorbing or nourishing surface, hence fission results to insure a relative increase of surface to the mass. Such division of cells goes on for a variable number of times, until finally the cell-protoplasm becomes enfeebled and worn out. In certain infusoria the number of divisions may be from 150 to 450; after that conjugation is necessary for a continuance of the

method. From such observations one may reason that sexual reproduction insures a fresh conjugation of protoplasm for each individual, thus keeping the standard up to the maximum.

Also *sexual reproduction* tends to preserve the type of the species; for if the individual were the offspring of but one parent, certain characteristics of that parent would be exaggerated in the course of several generations; but as the individual springs from two parents, it becomes the mean between those parents, with the result that the individual tends to become the composite of the entire species.

Fecundation: The junction of the male and female *elements* in sexual generation is called fecundation. At the time when the male and female discharge their respective elements it is not necessary that the parents should be in *juxtaposition.* In deep-sea fishes the female discharges her spawn; the male, which is destined to fecundate these ova, may be miles away and discharge his spermatozoa into the ocean; the male and female elements may float about until finally they meet, with the result that the ova become fecundated.

In fishes like trout, salmon, etc., the female lays her eggs on the spawning-bed, and later on the male deposits his elements directly on the spawn.

Still further along in the scale we find *juxtaposition essential,* the male grasping the female and both discharging their elements at the same time, and the ova are fecundated as soon as they leave the female.

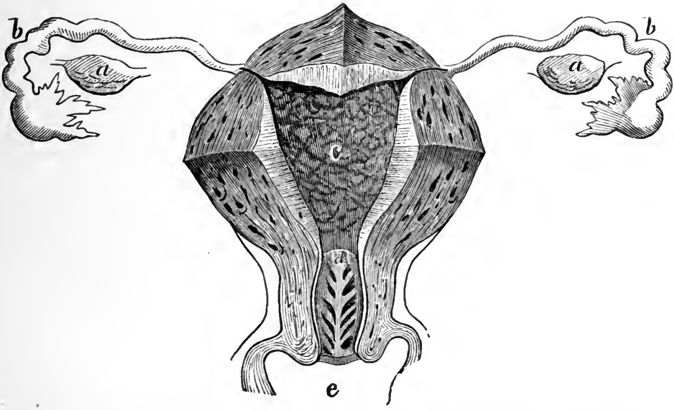
Of course, in "*viviparæ*" not only is juxtaposition essential, but there is an actual discharge of the male elements into the cavity of the female generative organs (such an act is called "*copulation*").

Human Female Organs of Generation.

The **female organs** consist of two *ovaries,* in which the ova are formed, and their oviducts or *Fallopian tubes,* which carry the ova to the *uterus,* in which they may develop if fecundated by the male; and the *vagina* for the reception of the male organ in *copulation* and for the subsequent discharge of the fœtus.

The **ovaries** are two organs lying one on each side of the uterus, attached to the broad ligament. In size they are about $1\frac{1}{2}$ inches long, 1 inch wide, and $\frac{1}{2}$ inch in thickness. Besides their attachment to the broad ligament, they are stayed in their position by folds or ligaments running to the

FIG. 134.



Generative organs of the human female. *a*, *a*, ovaries; *b*, *b*, Fallopian tubes; *c*, body of the uterus; *d*, cervix; *e*, vagina (upper part).

fundus of the uterus and to the fimbriated extremity of the Fallopian tube.

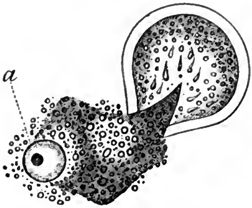
If an ovary be minutely examined, it is seen to be a *ductless gland* in which the composing elements are: (1) A *stroma* of connective tissue and unstriped muscle-cells, and with them a great number of peculiar spindle-shaped branching cells; and (2) the glandular portion, characterized by the Graafian follicles.

The **Graafian follicles** are best observed during the child-bearing age. They lie in the periphery, and present various appearances as they are more or less matured. Some are large enough to be seen by the unaided eye, while others are very minute. In the matured follicle the interstitial tissue will be found to have collected in a wall, quite well defined, which is lined by an *epithelial layer;* and upon one of this

layer epithelium is heaped up into a mass, the *germ-hill* (cumulus or discus proligerus), which contains the ovum. The remainder of the follicle is filled with a colorless fluid.

As the Graafian follicles mature they approach, and often project above, the surface of the ovary. The fluid contents of the follicle increase and the wall becomes thinner over it, until finally it bursts, and the ovum with some of its surrounding epithelium escapes.

FIG. 135.



Human ovum, ruptured by pressure, showing the vitellus partially expelled, the germinative vesicle, with its germinative spot, at *a*, and the smooth fracture of the vitelline membrane.

The ovary is covered on one surface with a thin layer of epithelium (*the germinal epithelium*), and not by the peritoneum. This is of great importance in the life of the ovum, for it renders it possible for it to enter the orifice of the Fallopian tube without interfering with the peritoneum and without having to pass so dense a structure.

From puberty to the menopause the formation of new Graafian follicles is continuous, and a very great number are produced; but many do not develop ova, and so waste away without going through the changes described.

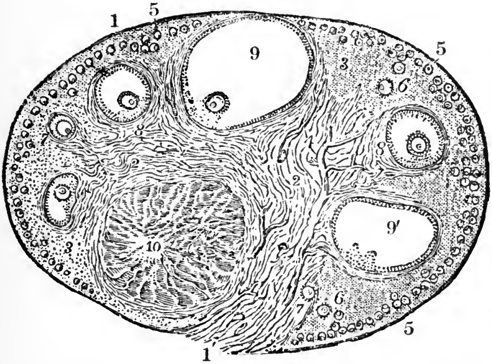
The **ovum** is a very highly developed cell, which is derived from the germinal epithelium covering the ovary. In the development of the ovary this epithelium dips into the surface of the organ, and a certain portion is finally walled off by growth of the surface-cells. Thus a ball of epithelial cells is introduced into the body of the organ, and one cell develops the ovum, the rest going on to make up the Graafian follicle and the germ-hill (see 5, 6, 7, 8, 9, Fig. 136).

If the ovum in its perfected state, as it leaves the Graafian follicle, be examined, it will be found to be a minute globular cell containing a nucleus and nucleolus as well as a cell-membrane.

In *diameter* the ovum is a little less than $\frac{1}{100}$th inch. The component parts of the ovum have received special names and are worthy of separate description.

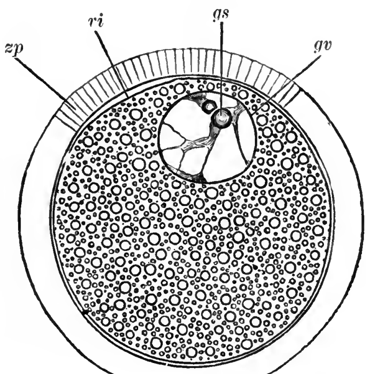
The *cell-wall* is called the "*zona pellucida,*" or "*radiata,*" or

FIG. 136.



Section of the ovary (after Schrön). 1, outer covering; 1′, attached border; 2, central stroma; 3, peripheral stroma; 4, bloodvessels; 5, Graafian follicles in their earliest stage; 6, 7, 8, more advanced follicles; 9, an almost mature follicle; 9′, follicle from which the ovum has escaped; 10, corpus luteum.

FIG. 137.



Semi-diagrammatic representation of a mammalian ovum highly magnified. *zp*, zona pellucida; *vi*, vitellus; *gv*, germinal vesicle; *gs*, germinal spot.

"*vitelline membrane,*" and is a thick hyaline membrane enclosing the cell-body.

The *cell-body* is a mass of granular protoplasm, called the "*vitellus*."

The *cell-nucleus*, or "*germinal vesicle*," is a somewhat large transparent and well-defined body set somewhat eccentrically in the vitellus or egg-yolk.

The *nucleolus* of the cell is called the "*germinal spot*." The latter is a small, dark, almost opaque spot, situated in the nearly transparent fluid nucleus (Fig. 135).

Fallopian tubes: The tubes are about $3\frac{1}{2}$ inches in length, and extend from the fundus of the uterus laterally on each side. The calibre of the tubes gradually narrows from without inward, until at the uterus the opening is very minute. The external covering is peritoneum, but the lining is mucous membrane having ciliated epithelium. The outer end of the Fallopian tube is free and fringed—the fimbriated extremity.

The *function* of the fimbriated extremity is to grasp the ovary, and thus act as a funnel into which the ovum is discharged by the rupture of the Graafian follicle. It frequently happens that ova are expelled from the ovary and miss the mouth of the fimbriated end of the Fallopian tube, either because the fimbrium failed to grasp the ovary at the proper point or else had failed altogether to make any attempt to grasp the ovary. Under such circumstances the ovum lodges in the peritoneal cavity and usually dies, but occasionally becomes impregnated.

Between the peritoneal covering of the Fallopian tube and its mucous membrane lining is a coat of circular and longitudinal muscle-fibres. These muscle-fibres serve to force the ovum received by its fimbriated end along the tube, and so into the uterus. This action is also aided by the ciliated epithelium.

The **uterus** is a somewhat pear-shaped organ, and is about 3 inches in length, its wider part being about 2 inches wide and the cervix 1 inch. It is described as consisting of a fundus, body, and cervix. This body unites the fundus with the cervix, which extends into the vagina.

It is covered over nearly all of its external surface with peritoneum. Its bulk is made up of unstriped muscle, which occurs in longitudinal and circular bundles and layers. This

muscular tissue increases enormously during pregnancy, and by its strength helps to extrude the fœtus. The lining is of mucous membrane, which is formed in its superficial layer of ciliated columnar epithelium. In the mucous membrane of the cervix are a number of follicles which secrete a viscid, tenacious mucus, by which the os uteri is frequently found to be plugged.

The **vagina** is a musculo-membranous canal about 5 inches long, extending from the uterus to the external genitals. It is lined with mucous membrane, which in the ordinary contracted state is thrown into folds, its anterior and posterior walls being in contact. There is considerable erectile tissue in the mucous membrane. At the orifice of the vagina externally is a sphincter which only partially contracts it, and besides this there are longitudinal and transverse unstriped muscle-fibres in the submucous tissue. The outlet of the vagina is sometimes also partially closed in the virgin by the *hymen*, a fold of mucous membrane.

The **external organs of generation** are not immediately connected with the function of reproduction, and may be enumerated as the labia majora, labia minora, and clitoris.

Functional activity of female generative organs: Under this heading we have two manifestations to study—viz., *ovulation* and *menstruation*. Both of these events are closely associated with the childbearing period of a woman's life, and are also closely associated together. Much dispute has arisen over the association of menstruation and ovulation, and without attempting to weigh the comparative merits of the different theories we shall accept and describe only those most generally accepted.

Menstruation is a phenomenon inherent in all women between puberty and the menopause. It consists of a flow of blood from the uterus, together with an exfoliation of part or of the whole of the mucous membrane of the uterus. At the menstrual period there are, in addition, certain physical and psychical manifestations involving to a more or less degree the entire individual.

By **puberty** is meant that age at which a woman begins her functional (childbearing) existence. In temperate climates

we may say the average age is fourteen years. In southern countries it is somewhat earlier, and in the arctic regions a year or two later. However, no fixed rule can be given, as the time of arrival at puberty varies with every individual, depending on race, temperament, hygiene, and general surroundings.

At puberty is the time when the girl changes into the woman. The event is not accomplished at once, but extends over considerable time. The girl undergoes a gradual change in figure, the hips broaden, the breasts develop, pubic hair grows abundantly, etc. She now begins to realize the difference in sex between herself and her boy companions. She becomes more bashful and retiring. Also for the first time a menstrual flow is noticed. At first the menstrual periods are scanty and irregular, but after a few months they settle down to the characteristic rate and duration. The girl is now a woman.

By **menopause**, or *climacteric*, is meant the physiological cessation of the menstrual flow. The woman's functional activity is over. The ovaries become smaller; no more Graafian follicles are developed; the Fallopian tubes atrophy; the pubic hair becomes thin and straight. The age of menopause varies as does the age of puberty; in general we may say the earlier the puberty the earlier the menopause, and *vice versa*. In temperate climates the average period for the arrival of the menopause is at the age of forty-five years. Thus we see a woman's functional activity lasts thirty years.

Frequency of menstruation: When once established menstruation occurs on the average every twenty-eight days although it is not without the bounds of normal health for some women to have a menstrual flow every twenty-one days, and others do not menstruate oftener than once in six weeks. Menstruation is in abeyance during *pregnancy* and *lactation*.

Duration of menstruation: The menstrual flow lasts on an average five days, the amount of blood lost gradually increasing until the third day, and then gradually diminishing.

Nature of menstruation: At the beginning of menstruation there is a general congestion of the generative organs, including the breasts. A few days before menstruation there

has developed a hypertrophy of the mucous membrane (superficial layers) of the uterus. At the beginning of the menstrual period this hypertrophied mucous membrane is gradually shed, leaving its underlying vessels exposed, and they bleed. At the end of menstruation a new mucous membrane is developed. The shed mucous membrane is called the "decidua menstrualis." During menstruation, especially at the beginning of the period, the woman is apt to be peevish, irritable, complains of headache, loss of appetite, and a sense of pelvic oppression that may even amount to severe pain.

Character of menstrual discharge: It is a thin, bloody fluid of a dark color and having a peculiar odor. It consists of blood, epithelium, and mucus from the uterus and vagina, together with the decidua menstrualis. The blood does not clot.

Ovulation: The commonly accepted theory is that about or shortly before the age of puberty the Graafian follicles begin to discharge their ova, and that this process continues until the menopause. Doubtless many Graafian follicles only partially develop and atrophy without discharging mature ova. The *frequency* with which well-developed ova are discharged is the subject of much dispute. The most conservative view is that there is one mature ovum discharged for each menstrual epoch. On the other hand, other embryologists claim that there is an almost daily discharge of ova, but only a few enter the Fallopian tubes, while the rest are lost in the peritoneal cavity. Whichever view the student cares to follow is immaterial, but nevertheless we must agree that only about as many mature ova reach the uterine cavity as there are menstrual epochs.

Life-history of the unimpregnated ovum: On leaving the ovary and entering the Fallopian tube the ovum is surrounded by a few cells derived from the discus proligerus of the Graafian follicle. These cells may serve as a source of nourishment, but soon disappear. There are now certain changes to be observed in the ovum itself; first, the vitelline substance seems to contract slightly, so as to leave a narrow rim or space between the vitellus and zona pellucida—the perivitelline space.

At this time the nucleus or germinal vesicle undergoes a karyokinetic division into two parts, one part then being expelled from the ovum proper into the perivitelline space as a "*polar body*," the remaining portion of the original nucleus, again subdividing into two parts by karyokinesis, with the protrusion of one part as a second "polar body." What is now left of the original nucleus is the "*female pronucleus*"; the polar bodies are apparently useless. Up to this point all ova develop alike, and now are fit for impregnation. If impregnation does not take place, the ovum dies and is cast off. If impregnation does occur, there is further development of the ovum, as we shall see in a later paragraph.

Corpus luteum: After the escape of an ovum there is an effusion of blood into the cavity of the Graafian follicle. The clot which follows is disposed of by the same retrogressive processes which extravasated blood may undergo in any part of the body. The serum is absorbed, the cells disintegrate, and the coloring-matter is in part taken up by the tissues and in part crystallizes or takes up other constituents, and presents variations of coloring. Hand in hand with these changes in the blood go important changes in the surrounding tissues. The epithelial cells which are left behind proliferate and form a sort of yellowish, very vascular tissue, which presently undergoes fatty degeneration. This yellow mass surrounding and enclosing the remains of the extravasated blood constitutes the *corpus luteum*, and as it disappears its place is occupied by a dense, firm connective-tissue cicatrix, which may be pigmented.

The changes described above are those that take place if the ovum *fails to become impregnated*. If, on the other hand, *fecundation occurs*, the corpus luteum undergoes certain characteristic changes, widely differing from the degeneration of the corpus luteum of non-pregnancy. If the ovum be impregnated, the corpus luteum then does not degenerate and disappear rapidly as after menstruation, but continues fully as large as at the beginning for several months, and at the end of pregnancy still remains as a clearly marked body. This is shown in the following table from Dalton:

	Corpus Luteum of Menstruation.	*Corpus Luteum of Pregnancy* (Dalton).
At the end of three weeks.	$\frac{3}{4}$ inch in diameter; central clot reddish; convoluted wall pale.	
One month.	Smaller; convoluted wall bright yellow; clot still reddish.	Larger; convoluted wall bright yellow; clot still reddish.
Two months.	Reduced to the condition of an insignificant cicatrix.	$\frac{7}{8}$ inch in diameter; convoluted wall bright yellow; clot perfectly decolorized.
Four months.	Absent or unnoticeable.	Size about as at two months; clot pale and fibrinous; convoluted wall dull yellow.
Six months.	Absent.	Still as large as at the end of the second month. Clot fibrinous. Convoluted wall paler.
Nine months.	Absent.	$\frac{1}{2}$ inch in diameter; central clot converted into a radiating cicatrix; external wall tolerably thick and convoluted, but without any bright yellow color.

Connection between ovulation and menstruation: Whether ovulation depends upon menstruation or menstruation upon ovulation, or whether either has any connection with the other, is a matter of lengthy controversy.

However, the general view is that both ovulation and menstruation are the result of a common cause (cause unknown), but either may exceptionally occur without the other.

It is generally accepted that ovulation, or discharge of ovum from a Graafian follicle, takes place a few days before the onset of the menstrual period.

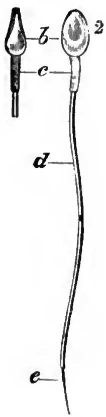
Human male generative organs.

The **generative organs of the male** consist of the two *testicles,* which produce the *seminal fluid;* and the *vas deferens,* or duct leading from each to join with the duct of the corresponding *seminal vesicle,* in which the secretion is stored (?) until it is discharged through the *penis* and the *prostate gland.*

Testicles: Each testicle is made up of a dense connective-tissue framework and a secreting portion. The connective-tissue stroma, *tunica albuginea*, surrounds the outside of the organ, and sends incomplete partitions into the central portion of the organ, dividing it into a number of communicating cavities. In these cavities are winding *tubules* which constitute the secreting portion of the organ. These tubules inosculate in a sort of mesh (rete testis), and finally all unite in the epididymis. The secreting tubules are called the *seminiferous tubules.*

Each tubule has, in the active organ, a limiting membrane, upon which are a number of layers of flattened cells. Internal to these are *seminal cells* in two or more layers. The seminal cells contain nuclei which are capable of division, so that each nucleus may develop several new nuclei. The nuclei are the spermatoblasts, or cells from which the spermatozoa originate. The cells before the division of the nuclei resemble the ordinary cuboid epithelium, and it is in the superficial layers (*i. e.*, toward the lumen of the tubuli) that this function of the cells takes place.

FIG. 138.



Human spermatozoon. 1, in profile: 2, viewed on the flat; *b*, head; *c*, middle piece; *d*, tails; *e*, end-piece of the tail.

The seminiferous tubules all converge toward the *epididymis*, a tortuous tubule which is lined with mucous membrane, and lies beside the testis in a long, convoluted mass which may be unravelled, and is found to be about 20 feet long. This empties contents, or rather continues on, into the *vas deferens*, which conveys the semen to the junction with the seminal vesicle. During this passage the mucous membrane adds a viscid mucous secretion in which the spermatozoa are liberated and, so to speak, diluted.

Spermatozoa: In the seminiferous tubules the developing spermatozoa may be seen with the heads all united in the cells from which they arise, the tails projecting
the cavity of the tube. Bu
separated. They then consist of a head and a

In length they are about $\frac{1}{500}$th to $\frac{1}{400}$th of an inch. The head is somewhat elliptical and the tail gradually tapers. In other animals than man the size and form vary from those of man, though in a general way they conform.

There is a very active *vibratory motion* of the tail of the spermatozoon, which allows it quite free motion in a fluid medium. It is by this swimming motion, in which it may be compared to a tadpole, that the seminal cell is able to reach the ovum against the action of the cilia in the uterus and Fallopian tube.

Seminal vesicles: They are tubules which join the vasa deferentia, and lie upon the base of the bladder, emptying into the urethra by the ejaculatory ducts through the prostate gland. In structure the vesiculæ seminales are convoluted and dendritic. They are lined by a mucous membrane and are convoluted and folded so as to present a sacculated appearance.

Prostate gland: It is a gland lying at the base of the bladder and surrounding the urethra at its beginning. It has the general structure of the glandular organs, and in addition a considerable amount of muscular tissue. Its acini empty into ducts which empty into the urethra. Its function is not exactly known.

The **penis** consists of three more or less cylindrical bodies of erectile tissue enclosed in fibrous sheaths. The two *corpora cavernosa* lie above, and receive between them, below, the *corpus spongiosum*, in which the urethra is contained. The *glans penis* is continuous with the corpus spongiosum. The covering of the penis is of loose skin, but over the glans penis and lining the prepuce it resembles mucous membrane. In this region there is an abundant subcutaneous nerve-plexus, and the Pacinian bodies are quite numerous, so that it is possessed of acute sensibility.

The **urethra** extends from the bladder through the corpus spongiosum to the end of the penis. It is lined with mucous membrane, and is furnished in its deeper layers with numerous muscular fibres. There are a number of ducts of glands [illegible] it whose function is not fully understood, though [illegible]m is supposed to be added to that of the seminal [illegible] make up the semen.

Erectile tissue of the penis: The erectile tissue consists of a system of distensible vacuoles containing venous blood, lying in the interstices of a fibrous connective tissue. The erector penis muscle by its contraction compresses the veins of the organ, and the veins become turgid with blood. The arteries enter the structure of the erectile tissue along the pubic bone, and are not pressed upon by the contraction of the muscle.

Impregnation in the Human Species.

Impregnation, or fecundation, are the terms applied to the junction of the male and female elements (spermatazoon and ovum), by virtue of which the joined elements become one, and by developmental growth eventually become an individual of the species. If no junction of spermatazoon and ovum takes place, each dies and is cast off. If, however, the ovum is fertilized by the spermatazoon, a new life is begun.

Methods of fertilization: The methods by which the male spermatazoon and ovum are brought in contact vary for different classes of animals. As has already been mentioned, in some classes of *fishes* the female ejects her spawn and the male his elements, at different places, and owing to the ocean currents the male elements are brought into contact with the female elements. In *frogs* the male fertilizes the ova just as the latter leave the female. In *mammalia* the male introduces the spermatozoa into the genital passages of the female, and this act is called *coitus.*

Coitus: The act of coitus is preceded by a preliminary period of sexual excitement, more marked in the male, during which the penis becomes swollen, turgid, and erect. The penis is then introduced into the female vagina. As a result of muscular movements there is friction upon the delicate sensory nerve end-organs of the glans penis and clitoris, producing intense nervous sensations, leading finally to a climax of excitement on the part of both male and female that gradually fades away. During the climax (or orgasm) there is an ejaculation of seminal fluid on the part of the male into the upper end of the vagina of the female. There

is also a flow of secretion from the glands of Bartolini of the female, and also, presumably, a rhythmical opening and closing of the cervical canal.

Site of impregnation: Although the seminal fluid of the male is lodged, at the close of coitus, in the vagina of the female, the spermatozoa are not yet in contact with the ovum. By virtue of their inherent mobility the spermatozoa travel along the cervical canal into the cavity of the uterus, there to meet the ovum. The spermatozoa may even travel along the Fallopian tubes, impregnating the ovum in the lumen of the tube; or may even leave the tubes by their fimbriated ends and impregnate the ovum on the surface of the ovary.

Time of impregnation: Probably immediately before the menstrual period; but owing to the fact that both the female and the male elements may remain in the genital passages of the female for some days in a healthy condition, it is difficult to fix the time of actual impregnation of the ovum.

Impregnation is generally supposed to occur a short time before menstruation, on the following grounds:

(1) It is probable that in most instances the rupture of the Graafian follicle occurs just before the menstrual period. (2) The uterus is in the most favorable condition to sustain the fecund ovum at that time, because of the presence of the decidua menstrualis. (3) Among the Jews, a remarkably prolific race, coitus is prohibited by the religious law for a week after menstruation.

Details of impregnation: The spermatozoon travels along the uterus or Fallopian tubes until it comes in contact with the ovum. The spermatozoon, by lashing its tail, wriggles through the zona radiata (pellucida) of the ovum and enters the perivitelline space. Several spermatozoa may succeed in effecting an entrance as far as the perivitelline space; but beyond this, for some unknown reason, but one spermatozoon goes further and enters the vitellus proper; the others die. The spermatozoon destined to fertilize the ovum now loses its tail, and the head and centre-piece are called the *male pronucleus*. The male pronucleus and female pronucleus now fuse together in the centre of the egg and form the first segmentation-nucleus.

On the formation of the first segmentation-nucleus the act of *impregnation* is complete, and the subsequent changes in the growth of the ovum come under the head of "Development."

DEVELOPMENT.

Methods of study of development: The early development of the human ovum has not been studied with accuracy, but we have reasoned by analogy, from observations upon the lower animals. One method is to watch the changes in the development of the egg of the common fowl. This is on account of the accuracy with which the time of development may be watched, and the convenience to the observer of such simple growth by incubation compared with uterine growth. The processes of development are not materially different.

Segmentation: The most frequent site of impregnation is probably the Fallopian tubes, and while there the ovum receives a layer of clear albuminous material, which adds considerably to its bulk. This corresponds to the white of a hen's egg.

The next change which occurs in the impregnated egg is the splitting up of the vitellus or yelk, first in halves, then in quarters, and so on until the vitellus becomes a mass of minute granular-looking nucleated cells (Fig. 139). The segmentation of the nucleus precedes and continues with the corresponding change in the yelk.

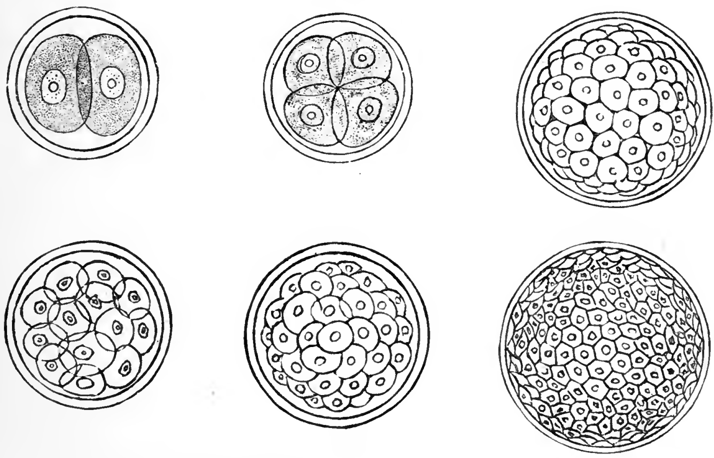
Germinal membrane: After the yelk has subdivided into a large number of cells these cells undergo a centrifugal action, with the result that they form a complete inner lining for the zona pellucida of closely packed polygonal cells, leaving a central clear cavity containing the vitelline liquid. This lining is the germinal or blastodermic membrane.

Site of segmentation: So far the ovum has probably remained in the Fallopian tube, but now descends into the uterus. The descent into the uterus is estimated to take place about ten days after impregnation.

Before studying the subsequent development of the *blastoderm*, let us see what changes have taken place in the lining of the uterus to prepare it for the reception of the ovum.

Changes in the uterine lining: The decidua menstrualis has been mentioned as specially suitable for the reception of the ovum. But if impregnation occur, it is not called by this name, as menstruation does not occur. It is then known as the *decidua vera*. It consists of a thick, succulent mucous membrane caused by the proliferation of the subepithelial cells. Into this decidua the ovum falls, and its shaggy chorion implants its villi in the crypts of the mucous mem-

FIG. 139.



Segmentation of the vitellus in the impregnated egg of the rabbit (Coste).

brane. The decidua soon envelops it, and the portion which is reflected over the ovum is known as the *decidua reflexa*.

Changes in the blastoderm: There appears at one point an opaque streak (Fig. 140), which is found to be due to the proliferation of the cells of the blastoderm. This is the *primitive trace*, and it grows in length and breadth.

The surrounding area of increased cell-proliferation is called the "area germinativa." The blastoderm—*i. e.*, that portion or area of the blastodermic membrane in which the *embryo* is actually developing—increases in area from the rapid proliferation of cells, and folds up at each end trans-

versely and at the sides longitudinally. These *folds* are of great importance, for it is in this way that the contour of the body is outlined, and if it were not for them the blastoderm would continue to develop as a flat surface. The transverse folds are at each end, and are known as the *head* and *tail* folds. The longitudinal folds define the outlines of the body (see Amnion). There also occurs a *constriction* of the entire ovum; above the constriction is the developing embryo, and below the constriction is the *yelk-sac* (see page 287). Together with these changes the cells of the

FIG. 140.

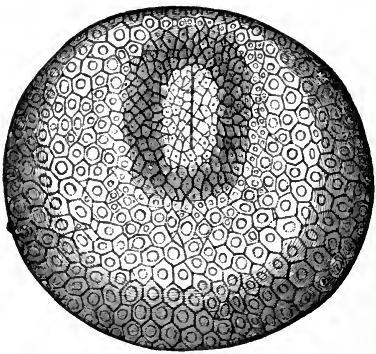


Diagram of the area germinativa, showing the primitive trace and area pellucida.

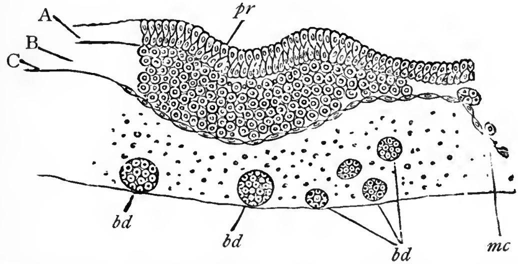
blastoderm and blastodermic membrane split up into three concentric layers—the *epiblast*, *mesoblast*, and *hypoblast* (Fig. 141); and along the axis of the primitive trace a groove is formed which is destined to become the cerebro-spinal axis. This is the *primitive groove*, or medullary groove.

Development of the medullary groove: Certain ridges or folds appear in the epiblast on either side (mesial to and smaller than the ones mentioned above). They continue to thicken, and finally coalesce dorsally, leaving a lining of cells within a *tube*. These cells develop the cerebro-spinal axis (cord and brain) and follow the curves of the blastoderm longitudinally. It is to be noticed that the enclosure of the spinal canal in

this way is by a folding process, and all through the process of development this peculiarity is very marked.

Meanwhile the mesoblast has developed a number of processes, which become a **primitive spinal column.**

Fig. 141.



Section of a blastoderm at right angles to the long axis of the embryo, near its middle, after eight hours' incubation (from Foster and Balfour). A, epiblast formed of two layers of cells; B, mesoblast, thickened below the primitive groove; C, hypoblast, formed of one layer of flattened cells; *pr*, primitive groove; *mc*, mesoblast cell; *bd*, formative cells in the so-called segmentation or subgerminal cavity (the line of separation between the epiblast and mesoblast below the primitive groove is too strongly marked in the figure).

Changes in the mesoblast: The mesoblast throughout a portion of its distance subdivides into two layers, one part of the split mesoblast adhering to the epiblast, while the remainder joins the hypoblast. The former is known as the *somatopleure,* and the latter as the *splanchnopleure,* and the included space becomes the pleuro-peritoneal cavity, which subsequently divides and differentiates to form the pleural, pericardiac, and peritoneal cavities.

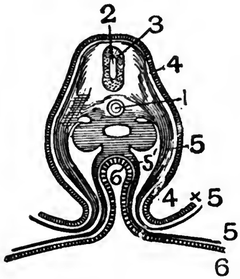
Structures derived from the epiblast: The *epiblast* develops into the epidermis and appendages of the skin, the great nervous centres, the nerves, and the principal portions of the organs of special sense—eye, ear, nose.

Structures from the mesoblast: The bones, muscles, fasciæ, and connective tissues of the body. It also develops the vascular stem. It must be remembered that very early in embryonal life this tissue divides to join with the epiblast and hypoblast, and we can therefore understand how it may develop the muscular structures of the intestinal canal.

Structures from the hypoblast: The epithelial elements of the glands and the mucous membranes lining the alimentary and pulmonary tracts.

Destiny of the splanchnopleure: The *splanchnopleure* (5′, Fig. 142) folds in over the remainder of the ovum, and so walls in, so to speak, the yelk-sac, which communicates freely with the interior of the embryo. Later on, after the formation of the amnion, the yelk-sac forms a blind pouch which is lined with hypoblast and has an external covering of mesoblast, as is shown at 6 in the accompanying cut. The upper 6

FIG. 142.



Transverse sections through the embryo chick, before and some time after the closure of the medullary canal, to show the upward and downward inflections of the blastoderm (after Remak) on the third day in the lumbar region. 1, notochord in its sheath; 2, medullary canal, now closed in; 3, section of the medullary substance of the spinal cord; 4, epiblast; 5, somatopleure of the mesoblast; 5′, splanchnopleure (the figure is placed in the pleuro-peritoneal cavity); 6, layers of hypoblast in the intestines, spreading also over the yelk; 4×5, part of the fold of the amnion formed by the epiblast and somatopleure.

is in the primitive gut, which derives its epithelial elements from the hypoblast and its muscular and serous coverings from the mesoblast.

Umbilical vesicle: After the constriction of the vitellus or ovum (page 285), separating the main portion of the vitellus from the cavity of the future alimentary tract, the constricted portion, or tube, is known as the "vitelline duct," and the rest of the vitellus is called the "umbilical vesicle," both at an earlier period of development being known as the *yelk-sac.*

From the latter the embryo derives its sustenance in the

earlier stages. Early in the development bloodvessels begin to form, and they ramify over the surface of the umbilical vesicle and help to absorb its contents.

Amnion: While one portion of the split mesoblast (splanchnopleure) unites with the hypoblast to form the splanchnoblast and alimentary organs, the outer layer (somatopleure) and epiblast are united to form the skin and walls of the body as the somatoblast. The somatoblast now folds up and around the embyro, *above* and lateral to the folds of the medullary groove already mentioned. It must be remembered, however, that the entire globe of the ovum is invested by the somatoblast, and that in folding up in this way its cells are in a

FIG. 143.

Diagram of the fecundated egg, farther advanced, *a*, umbilical vessel; *b*, amniotic cavity, not yet complete; *c*, allantois.

FIG. 144.

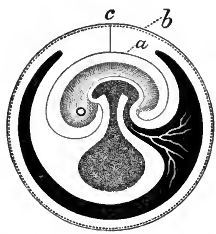


Diagram of the fecundated egg, with allantois nearly complete. *a*, inner lamina of amniotic fold; *b*, outer lamina of amniotic fold; *c*, point where the amniotic folds come in contact. The allantois is seen penetrating between the inner and outer laminæ of the amniotic folds.

measure raised away from the splanchnoblast. This "raising away" is further aided by the *sinking* of the embryo. The layers of the somatoblast fold up until they meet and unite behind the embryo, and in this way form a layer of membrane which lines the ovum and another layer which encloses the embryo (Fig. 143). This latter layer forms the true amnion. (This is better understood by reference to the cuts.)

Purpose of amnion: It covers the embryo in the early stages very closely; but soon becomes distended with a pale watery fluid, which serves to float the fœtus and give it equal me-

chanical support on all sides. The outer layer of the amnion becomes very thin and adheres to the chorion.

The *amniotic fluid* consists of water containing a small amount of albumin, urea and salt.

Allantois: During the development of the amnion from the somatoblast a change has occurred in the splanchnoblast. From near the caudal extremity of the primitive gut there has budded a small mass which develops rapidly, following the outline of the amnion (see Figs. 143, 144, 145), and grows fast to its chorion layer. This structure, *the allantois,* soon becomes very vascular and carries its bloodvessels to the chorion.

Fig. 145.

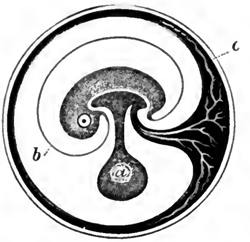


Diagram of the fecundated egg, with the allantois fully formed. *a*, umbilical vesicle; *b*, amnion; *c*, allantois.

Purpose of the allantois: It nourishes the growing embryo. The chorion (see below) has already become tufted with capillary loops, and has established a connection with the decidua of maternal growth. As the vessels of the allantois communicate more and more with the chorion, the embryo derives more of its sustenance from the mother, and the remains of the yelk-sac (umbilical vesicle) dwindle as the need is less and the substance is consumed (see Figs. 143, 144, 145).

Subsequent history of the allantois: After the development of the placenta the allantois dwindles away, all except the portion nearest the fœtus; this becomes the urinary bladder and the urachus (the latter, in the adult, is an impervious cord extending from the bladder to the umbilicus).

Chorion: the chorion is the outer zone of the ovum, and from its surface there project centrifugally a large number of villi.

The chorion consists of several layers which fuse into one vascular membrane: the allantois, the outer layer of the amnion, and the vitelline membrane are united in the chorion. As the embryo develops the vessels of the chorion become thinner on the side toward the uterine cavity, and more distinct on the opposite side. This change continues as the

embryo increases, until the *placenta* is formed by the branching of the embryonic vessels and the increase of the decidua at the corresponding point.

Association of decidua and chorion: In the deeper part of the mucous membrane of the uterus, at the implantation of the chorion, there are hollowed-out spaces or sinuses in the tissues, which communicate both with a maternal vein and an artery—that is, special arrangements are made for the rapid circulation of a large amount of blood in the uterine mucous membrane at the placental site. At the same time the glandular structures of the uterine mucous membrane are increased, and the follicles run deeply into the thick and succulent tissues.

The villi dip down and develop new tufts of capillaries in the deepened crypts of mucous membrane, so that the tufts of capillaries of the chorion may be said to resemble in a way a glove filled with fœtal blood dipping into a vessel filled with maternal blood.

The placenta: So far the villi throughout the entire surface of the ovum become associated with the decidua. Now, as development advances, that portion of the chorionic villi that is lined by the central portion of allantois grows still further in size, while the rest of the chorionic villi atrophy and disappear. The loops of bloodvessels of the allantois project into the villi of the chorion (like a finger into a glove), and thus are brought into closer contact with the blood of the decidua (maternal blood). The portion of villi of chorion containing the vessels of the allantois is the *placenta*.

Thus we see that the placenta consists really of two parts—a fœtal portion, consisting of fœtal bloodvessels contained in the chorionic villi; and a maternal portion, consisting of follicles or depressions in the uterine wall, surrounded by bloodvessels so enlarged as to form blood-chambers (uterine sinuses). The chorionic villi are lodged in the uterine follicles, or between the follicles, according to some observers.

Association of fœtal and maternal blood: The fœtal blood never comes directly in contact with the maternal blood. The two blood-currents are nearest each other while circulating through the placenta.

While in the placenta there are four layers of cells between

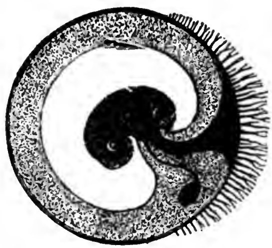
the maternal and the fœtal blood: 1, wall of chorion capillary; 2, cells of chorion; 3, cells of uterine follicle; and 4, wall of the uterine sinus.

Interchange between fœtal and maternal blood: Although there is no direct communication between the blood of the fœtus and that of the mother, nevertheless while passing through the placenta there is an exchange by osmosis between the mother's blood and the fœtal blood.

The mother's blood furnishes to the fœtal blood food and oxygen, and in turn removes the carbonic acid and excrementitious material which the fœtus must lose—that is, the placental circulation supplies the place taken in after-life by the alimentary and the respiratory tracts.

Umbilical cord: The umbilical cord or funis is the stalk connecting the placental with the fœtus, and its purpose is to be a framework or support for the umbilical arteries and veins. The tissues of the umbilical cord are formed from the vascular allantois, which carries the arteries and veins. It also has an external coating of the amnion and the shrivelled umbilical vesicle and its duct (Fig. 146). How this occurs will readily be seen by reference to the accompanying cut.

Fig. 146.



Human embryo and its envelopes at the end of the third month, showing the enlargement of the amnion.

At first two arteries convey the blood from the fœtus to the placenta, and two veins carry the purified blood from the placenta to the fœtus. Later on in fœtal life one of the veins is lost. At term the umbilical cord is a rope-like structure between 18 inches and 36 inches long, and consists of one vein and two arteries spirally twisted; the vessels are enclosed in a layer of jelly-like substance (Wharton's jelly), and the whole is surrounded by a connective-tissue sheath. The cord is about one-half inch in diameter.

Destiny of placenta: The fœtal part is almost all, excepting some of the capillary tufts which are torn off, discharged in

the after-birth; but the decidua is not entirely disposed of in this way, the portions remaining being in part absorbed and in part found in the *lochia* which occur for a few days after the birth.

When the placenta is expelled a part of the maternal tissue is left behind, and there is, of course, a loss of the blood contained in the uterine sinuses, but the general balance of the circulation is not disturbed at childbirth. The reason for this is the oblique entrance of the placental vessels. They enter the sinuses at an angle, and are therefore compressed by the muscular tissue of the uterus in its contracted state.

Appearance of placenta: The placenta at term appears as a thick, cake-like disk of vascular tissue. Its maternal and fœtal portions are so intermingled that they cannot be separated. In size it covers about one-third of the uterine wall.

Period of placental formation: The placenta is formed at about the third month of pregnancy. Before that time the chorion is covered by the decidua reflexa and nourishes the embryo, but as the placenta becomes more developed other parts of the chorion atrophy.

Fœtal Circulation.

Types of fœtal circulation: One meets with two distinct types of circulation in fœtal life: the vitelline circulation and the placental circulation. In both types the blood is the circulating medium driven on by the heart, the essential difference being the site where the fœtal blood is enriched. The vitelline circulation precedes that of the placenta, and as soon as the latter is formed the former disappears.

Vitelline circulation: In the vitelline circulation the vessels from the fœtus (omphalo-mesentric vessels) pass over the yelk-sac and carry nutrition to it from the growing organism. The vitelline circulation in the human ovum is not very long-lived, for the chorion is early formed and the stock of nutrient protoplasm in the yelk-sac is very small.

Placental circulation: In the placental circulation the fœtal

blood is purified and enriched by osmosis with the maternal blood in the placenta.

Development of circulatory apparatns: Among the earliest changes in the blastoderm, occurring in the second week of impregnation, is the formation of bloodvessels and blood-corpuscles. This occurs by the proliferation of certain branched cells of the mesoblast, and these cells form a closed system of branching capillaries, their nuclei acquiring a red color and becoming the blood-corpuscles. This area is external to but connected with the embryo, and is known as the "area vasculosa."

FIG. 147.

Diagram of embryo and its vessels, showing the circulation of the umbilical vesicle, and also that of the allantois, beginning to be formed.

The **area vasculosa** extends all about the blastoderm upon the surface of the vitellus, and as the folds of the embryo occur the vessels are brought to enter the body through the space at which the vitellus is shut in to form the primitive gut. There are then two arteries and two veins which are known as the omphalo-mesenteric vessels. This form of circulation soon gives way to the placental, and the vessels passing to the umbilical vesicle waste, those belonging to that portion of the original vitelline cavity which forms the intestine, becoming the mesenteric vessels.

Formation of heart: About the time of the formation of the area vasculosa certain cells of the visceral layer of the mesoblast (splanchnopleure) develop a tube upon each side of the body, and these two tubes soon coalesce to form a single tube (Fig. 148), which receives two veins at its lower end and gives off two arteries at its upper. This is the primitive heart, and pulsations begin in it very feebly almost as soon as there is a trace of the originating cells. This structure soon develops a muscular tissue and a circulating fluid which shortly presents the character of blood.

The heart then bends on itself so as to assume a U-shape,

which shortly is twisted in such manner that the arterial end of the heart crosses in front of the venous (Fig. 149), and the loop suggests the outline of the ventricles.

In the next stage of development the septum between the ventricles grows, and separates the heart into two divisions; and at about the same time the auricles are developed and the valves become well marked. These changes occur in the fourth to the eighth week of embryonic life.

FIG. 148.

FIG. 149.

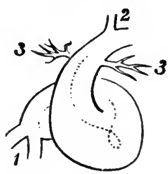


FIG. 150.

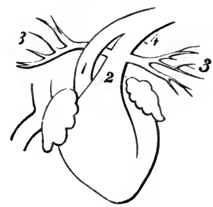


FIG. 148.—Earliest form of the fœtal heart. 1, venous extremity; 2, arterial extremity.
FIG. 149.—Fœtal heart bent upon itself. 1, venous extremity; 2, arterial extremity.
FIG. 150.—Fœtal heart still further developed. 1, aorta; 2, pulmonary artery; 3, 3, pulmonary branches; 4, ductus arteriosus.

Characteristics of placental circulation: After the cessation of vitelline circulation the needs of the fœtus are supplied by the placental circulation until birth. The placental circulation presents two prominent features in which it differs from adult circulation:

(1) In the arterial circulation some conditions of the heart and great vessels are necessary to modify the pulmonary circulation before the air enters the lungs at birth. (2) In the circulation of the liver the veins present modifications to allow for the return placental circulation.

Course of fœtal circulation: *Ductus venosus:* The fœtal blood, purified and enriched in the placenta, passes, by the umbilical vein in the umbilical cord, to the umbilicus. The umbilical vein then courses from the umbilicus to the under surface of the liver; here the vein divides into two parts. One portion of the blood enters into the liver-substance, and *after traversing its capillaries* is poured out by the hepatic

veins into the inferior vena cava. The other portion of blood passes *directly* from the umbilical vein *into the inferior vena cava* by means of a blood-channel, the *ductus venosus.*

Foramen ovale: The blood in the *vena cava inferior* empties into the right auricle of the fœtal heart. Instead of passing from the right auricle into the right ventricle, as is the case in the adult circulation, the blood from the inferior vena cava passes from the right auricle into the left auricle by means of an opening in the interauricular septum. The opening is called the "*foramen ovale.*" The flow of blood from the inferior vena cava through the foramen ovale and into the left auricle is facilitated by the fact that the inferior vena cava points almost directly into the foramen ovale.

The *Eustachian valve* also favors this peculiar course of the blood. The Eustachian valve consists of a crescentic fold of fibrous tissue covered with endocardium. The fold extends from a point between the opening of the superior and inferior venæ cavæ over to the lower and anterior margin of the foramen ovale. The base of the fold lies on the right auriculo-ventricular ring, and the concavity of the fold is directed upward. From its position the Eustachian valve acts as a guiding-groove or gutter for passing the blood from the inferior vena cava to the foramen ovale.

Ductus arteriosus: On entering the left auricle, the blood is passed into the left ventricle and thence into the aorta, to be distributed all over the body; but principally to the head and upper extremities.

The blood from the head and upper extremities returns to the heart by the superior vena cava. On entering the right auricle the blood from the superior vena cava passes in front of the stream that flows from the inferior vena cava to the foramen ovale, and enters the right ventricle.

The direction in which the superior vena cava points (toward the auriculo-ventricular ring), and also the Eustachian valve, are the factors that determine the separation of these two streams. On entering the right ventricle the blood from the superior vena cava is forced into the pulmonary artery toward the lungs. Before reaching the lungs this blood meets with a channel of communication between the pulmonary

artery and the aorta. Into this channel (*ductus arteriosus*) the larger portion of the blood in the pulmonary artery enters and mingles with the blood of the aorta; the remainder passes along the pulmonary artery to the structure of the lungs, which it nourishes, and thence back to the left auricle by means of the pulmonary veins.

Hypogastric arteries: The blood in the aorta that comes from the left ventricle passes, as has been already stated, largely to the head and upper extremities. The blood in the aorta that enters from the ductus arteriosus largely passes into the descending aorta.

On passing down the descending aorta, some of the blood enters the mesenteric arteries, and thence back to the venous circulation by means of the portal vein and the liver. Some of the blood enters the iliac arteries and nourishes the lower extremities; but the major part of the blood leaves the fœtal body by the *hypogastric arteries.* The hypogastric arteries are branches of the internal iliacs and course along the abdomen to leave the fœtal body at the umbilicus. On emerging from the umbilicus, the hypogastric arteries change their name, and are now known as the *umbilical arteries*, and form part of the structure of the umbilical cord on their way to the placenta.

Effects of arrangement of fœtal circulation: The liver, receiving the freshest blood (from the umbilical vein), is the best nourished of all the organs of the fœtus. The result is that the fœtal liver is vastly larger in proportion than the adult liver. Also the circulation of the blood is made more perfect, for the branches of the aorta given off to the head and upper extremities distribute blood from the inferior vena cava; while the ductus arteriosus, carrying the blood from the superior cava and right ventricle, enters the aorta in such a way that most of its blood is sent to the lower extremities and abdominal organs and umbilical arteries. In this way the deoxidized blood is sent back to the placenta for the renewal of its oxygen. The lower extremities are less well developed than the upper. There are probably two reasons for this: (1) the blood is less well aërated and less nutritious; (2) the internal iliac arteries, giving off the umbilical arteries, probably

divert a considerable portion of the blood-supply of the external iliacs which go to the lower extremities.

In addition, we note that, owing to the ductus arteriosus, only a little blood goes to the lung-tissues. The amount is quite sufficient to keep up the nutrition of the lungs, and as they have no function before birth they do not need a large blood-supply.

Change from fœtal to adult circulation: The respiratory centre in the medulla, which has been quiescent because it has been sufficiently well supplied with oxygen, is awakened as soon as the connection with the uterine sinuses is interrupted. As soon as the supply of oxygen sinks to a certain point, an impulse of inspiration is generated, and the infant breathes and the lungs assume a condition of partial expansion. With the diminished resistance in the expanded lungs the amount of blood in the pulmonary circulation increases, and, the amount passing through the ductus arteriosus diminishing, this is soon obliterated. At the same time, the blood returning to the left auricle increases in quantity, and the intra-auricular pressure is greater; then, too, the inferior vena cava sends less blood, for the ductus venosus no longer carries the blood from the placental circulation, and, therefore, the foramen ovale is not used, and is soon closed by the adhesion of its valve-like curtain. Thus, we have the adult circulation established in the place of the fœtal in consequence of the respiratory movements.

Also, owing to the division and occlusion of the umbilical cord, blood no longer passes through the umbilical vessels, with the result that the umbilical vein degenerates into a fibrous cord (round ligament of the liver). The hypogastric arteries remain pervious for the first part of their course, as the superior vesicle arteries; but the rest of their course is obliterated; they degenerate into fibrous cords.

Development of vertebral column: Early in the development of an embryo there is formed, beneath the medullary groove, in the mesoblast a thin thread of soft cartilage known as the chorda dorsalis, or *notochord*. This soon becomes included in a sort of fibrous sheath, and is the primary axis

around which the bodies of the vertebræ are developed. On either side of the notochord are developed small centres which subsequently split (mesoblastic somites). These are the *protovertebræ.* From these are developed the vertebræ and the heads of the ribs by the *inner part;* and by the *outer* (or posterior) *part* the muscles and skin of the back, the epidermis being derived from the epiblast.

The vertebræ are not formed by direct ossification of the protovertebræ, but they separate in such a way that adjacent protovertebræ each contributes half to the vertebra formed. That is, two protovertebræ form parts of two vertebræ, one above and the other below, and also form a whole vertebræ by their adjacent portions.

Development of cranium: The cranium is developed from the prolongation of the tissues over the protovertebræ to the cephalic end of the embryo. Here it develops three segments, corresponding to the three primary vesicles which are the forerunners of the brain. These centres of ossification are at the base of the skull, the bones of the vertex being developed from membrane.

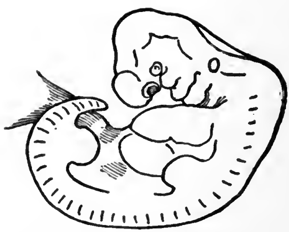
Development of the face: At the head fold of the embryo the mesoblast does not split into two parts, as below, but folds in from the side, covered without and within by the epiblast and hypoblast. These folds develop certain clefts from which the face is derived, the mesoblast furnishing the bone and muscle structures, and the epiblast the epidermis, while the hypoblast gives the mucous membrane which lines its cavities.

Immediately below the anterior cranial vesicle there occurs on either side a cleft in the lateral fold of the embryo extending to the vesicle for the eye. In the space of this cleft there is developed a sort of secondary cleavage of the parts, which by the rapid growth of the parts included between the clefts resembles a budding (Fig. 151). It is by the growth of these buds or processes that the outline of the face is formed. From each side sprouts the superior maxillary process, and the processes unite in the median line, and with the nasal or intermaxillary process from the upper border of the cleft. The portion below is cut off by a *branchial cleft,* below which is the mandibular process which forms the lower jaw.

When the processes do not unite as they should, various defects occur; most common are those about the mouth—viz., cleft palate and hare-lip, by failure of the superior maxillary processes to unite or by failure of the intermaxillary process to unite with the maxillary.

The *other branchial clefts* do not persist in later life. They become closed as they accomplish their use in developing certain organs: as pathological factors, however, we are often convinced of their non-union or of flaws in their development, cysts and tumors of various kinds and certain fistulæ being attributable to this cause.

Fig. 151.



Development during first month.

Development of the extremities: They develop as buds from the somatoblast early in fœtal life, and the formation of the joints by cleavage, and lesser details of structure are gradually worked out. At about the third month the separation of the fingers and division of the extremity into joints is about completed. The arm develops somewhat in advance of the leg, and grows rather more rapidly in the earlier period of intra-uterine life.

Formation of the spinal cord: It will be remembered that the medullary canal encloses in its cavity cells from the epiblast which line it. These cells by proliferation and differentiation develop nerve-cells and nerve-fibres, the latter at first not medullated. The cells also gradually close in upon the medullary canal, and form a central lined with epithelium, a layer of nerve-cells (gray matter) and a layer of nerve-fibres (white matter).

When the spinal cord first appears it fills the entire spinal canal, but at the time of birth the cord has apparently not grown so rapidly as the vertebral column, for it then ends at the third lumbar vertebra, and in the adult it ends at the first. Thus we are able to explain the apparent origin of the spinal nerves above their point of exit from the canal, and the increasing obliquity of the nerves from above down, until finally, in the tuft of vertical nerves below the extremity of the cord, we see the extreme degree of this peculiarity.

Development of the spinal nerves: The axis-cylinders arise from cells of the epiblast lining the medullary groove. Before the closure of this groove to form the medullary canal an offshoot from the epiblast may be observed, which is the source of the posterior nerve-roots; and they become attached to the cord as it develops. The anterior roots spring from the cord after it has developed fibres. The two roots then join and the nerve grows out into the mesoblast.

Development of the cranial nerves: In much the same way the cranial nerves arise primarily, except the nerves of special sense. In function the motor nerves seem to form a sort of anterior root for the sensory, so that they may be arranged in pairs corresponding to the anterior and posterior roots of the spinal nerves; and it does not seem entirely fanciful to regard their development as somewhat similar, thus:

Third, fourth, sixth and seventh, motor; fifth, sensory. Twelfth, motor; ninth, sensory. Eleventh, motor; tenth, sensory.

Development of the Brain.

It has already been shown how from the growth and fusion of the two sides of the primitive medullary groove a tube is formed; this tube representing the cerebro-spinal axis. Starting with this hollow cylindrical tube, closed at both ends, the spinal cord and brain are formed as a result of changes in the size of the lumen of the tube, alternate thickenings and thinnings of the walls of the tube, and various foldings and reduplications of the tube on itself.

Earliest rudimentary brain: The first demarcation between brain and spinal cord consists of a widening of the medullary canal at its anterior end. At the same time this primitive brain is subdivided into three portions by two transverse constrictions. The three chambers are known as the *anterior primary vesicle, middle primary vesicle,* and *posterior primary vesicle* (Fig. 152).

FIG. 152.

Formation of the cerebro-spinal axis. 1, anterior primary vesicle; 2, middle primary vesicle; 3, posterior primary vesicle.

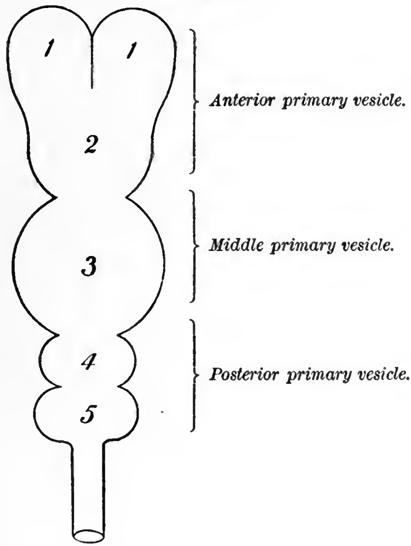
Secondary vesicles: As the result of further development the posterior primary vesicle is subdived into two parts by a transverse constriction. The anterior primary vesicle is also further developed by a forward growth of two projections, one on either side of the median line (hemisphere vesicles, Fig. 153).

Ventricles of the brain: The various *ventricles* of the brain are the successors of the original lumen of the cerebral axis. Thus we see that the lumen of the prosencephalon is known in the developed brain as the *lateral ventricles.* The lumen of the thalamencephalon is the *third ventricle,* and the communication between the two lateral ventricles and the third ventricle is called the foramen of Monro. The lumen of the mesencephalon (mid-brain) becomes the aqueduct of Sylvius. The cavity of the epencephalon (pons and cerebellum) and of the metencephalon (medulla) is the fourth ventricle.

Development of the walls of the cerebral tube: Commensurate with the division of the primary brain into its vesicles, there are changes going on in the walls of the tube. These changes consist of thickenings at some parts and thinnings at others. Thus the prosencephalon shows a more or less uniform increase in thickness, destined to become the substance of the cerebral hemispheres, corpora striata, etc.

The pons Varolii is a great increase *ventrally* of the wall of the epencephalon, while the cerebellum is a corresponding *dorsal* projection of the same vesicle.

FIG. 153.



Formation of secondary vesicle. 1, 1, prosencephalon; 2, thalamencephalon (diencephalon); 3, mesencephalon; 4, epencephalon; 5, metencephalon.

I. Anterior primary vesicle.	1. Prosencephalon.	Cerebral hemispheres, corpora striata, corpus callosum, fornix, lateral ventricles, olfactory bulb.
	2. Thalamencephalon.	Thalami optici, third ventricle, optic nerve.
II. Middle primary vesicle.	3. Mesencephalon.	Corpora quadrigemina, crura cerebri, aqueduct of Sylvius.
III. Posterior primary vesicle.	4. Epencephalon.	Cerebellum, pons Varolii, anterior part of fourth ventricle.
	5. Metencephalon.	Medulla oblongata, posterior part of fourth ventricle, auditory nerve.

The preceding table enumerates the changes described above.

The **roof of the fourth ventricle**, in its lower half, is described as consisting of but a single layer of epithelial cells. This is a result of a thinning of the dorsal wall of the metencephalon.

Folding of the brain-axis: So far we have described the brain as consisting of a straight tube with various constrictions and changes in the thickness of its walls. But the development is not so simple as that. The brain is enclosed in an unyielding box (the skull), which develops and grows at the same time that the brain grows, but not commensurately. The brain tends to grow in the direction of its long axis, but the skull grows as a sphere; hence to accommodate itself to the containing cavity, the brain must fold on itself—*i. e.*, coil up. So changes take place, with the result that the *cerebral hemispheres*, instead of projecting anteriorly, grow upward and backward so as to overlie the third ventricle. There is also a partial turn at the junction of the mesencephalon and epencephalon.

Convolutions of cerebrum: The same explanation (different rates of growth of brain and skull) serves to account for the presence of the cerebral convolutions. The surface of the cerebrum is "puckered," as it were, in order to be squeezed into the skull.

Development of the eye: About as soon as the cerebral vesicles are distinctly formed a budding of two projections—one from either side of the anterior vesicle—occurs. These are the primary optic vesicles. They are formed before the vesicles which make the hemispheres (prosencephalon). The projections approach the external epiblast, and at that period consist of a finger-like process having a globular dilatation at the end. This subsequently forms the optic nerve and the retina.

Opposite the optic vesicle the superficial epiblast is depressed and forms a sort of pit, forcing the optic vesicle to fold in upon itself. The follicle of epiblast is shut off at the surface, and a ball of its substance left in the cup of the in-

folded optic vesicle. This ball forms the rudimentary lens, and the anterior layer of the vesicle is the retina.

The muscular and vascular structures, as well as the connective tissue and humors, are derived from the mesoblast, which in part enfolds the ocular vesicle and in part enters it between the lens and the edge of the cup-like depression. The cornea is of later formation, and is derived from the epiblast of the skin.

Development of the auditory apparatus: Very early in the life of an embryo there is a depression on either side of the head which passes through the same process as that mentioned for the crystalline lens and for the germinal epithelium in the formation of ova. The mass of epiblast thus separated forms the epithelium of the labyrinth and vestibule, the surrounding mesoblast furnishing the bony and muscular structures. The auditory nerve is developed with other cranial nerves, and grows in to its end-organs from its central origin.

Development of the olfactory apparatus: In a similar way to the internal ear and the lens. The nasal fossa is primarily a depression in the superficial epiblast, which widens and deepens and receives the nerve-filaments from the olfactory lobe. This lobe is originally a bud from the prosencephalon. The primary olfactory depression continues to widen until it opens into the mouth, and is again shut off by the growth of the "branchial arch," which forms the superior maxilla. The nose is similarly derived from the mesial and lateral nasal processes.

Development of the alimentary canal: As has already been explained, the primitive alimentary canal is formed from the involution of the splanchnopleure, and is really a portion of the yelk-sac partially shut off from the rest. It is at each end a blind pouch which follows the head and tail folds. The portions have received the names *fore-gut* and *hind-gut* as they occupy one or other of these folds.

The *fore-gut* joins with the mouth-cavity by the folding back of the epiblast in the formation of the stomadœum, and from it are formed the pharynx, œsophagus, and stomach.

By a similar involution of the epiblast the anus and lower

part of the rectum are formed, into which the *hind-gut* opens to complete the alimentary tract.

The œsophagus is sometimes impervious at birth, and the rectum or anus may also be imperforate. This is caused by the non-union of the segments developed from the epiblast with those developed from the hypoblast.

Glands of the alimentary tract: (1) The *salivary glands* are developed from the epiblast lining the oral cavity. They appear primarily as a simple tube which develops branches, about which the alveoli are formed.

(2) The *pancreas* is similarly developed from the hypoblast of the fore-gut.

(3) The *liver* is primarily a protrusion, into a mass of mesoblastic tissue, of the hypoblast of the fore-gut, which appears as soon as the bloodvessels begin to show themselves. The omphalo-mesenteric vein, from the umbilical vesicle, breaks up into a capillary plexus in this same tissue, and the hepatic cells develop about it.

Derivation of the lungs: The lungs first appear as a bud at the junction of pharynx and œsophagus which soon forms a separate tube (the trachea). The cells from the hypoblast extend into the surrounding mesoblast, and it is from this structure that all of the tissues of the lungs, except its epithelium, are formed.

The **Wolffian body** is first seen as early as the third week as a series of transverse tubes which develop in the cells of the mesoblast, just inside of its division into parietal and visceral layers, on each side of the vertebral column. It is not a permanent organ. Internal to it develop the internal organs of generation, while behind the Wolffian body the rudimentary kidney develops.

The Wolffian body is a sort of temporary kidney. At first it is a large vascular body, resembling the kidney in structure, and opens by its tubes (outer ends, the inner ends being blind) into the *Wolffian duct*, which leads to and opens into the cloaca. At about the sixth week of fœtal life the kidney begins to grow and the temporary organ to atrophy. As this occurs a duct for the kidney (the ureter) is developed from the Wolffian duct. The use of the organ seems to be that of

a temporary kidney; but by the end of the third month it has been replaced by the permanent organ, and has almost entirely disappeared.

Formation of the internal genitals: The body (germinal epithelium) which appears on the inner side of the Wolffian body is the nucleus of the future testicle or ovary, while along the outer side are formed two ducts (Müller's and the *Wolffian*), which pass down to the cloaca or lower end of the hind-gut. At first it is impossible to determine the sex of the fœtus.

If the fœtus is to become a female, the ducts of Müller join to form the uterus and vagina, while the ununited portions remain as the Fallopian tubes. The Wolffian ducts are rudimentary in the female and appear as the ducts of Gärtner.

On the other hand, if the male type is to be formed, the *Wolffian ducts* become convoluted tubules, and each is attached to the testis as the epididymis and vas deferens. Müller's duct is rudimentary in the male, and is only found as the sinus pocularis and the hydatids of Morgagni.

Formation of external genitals: In both sexes in early fœtal life the external genitals are alike, consisting of a body resembling a penis with a fold of skin at either side. *In the female* this body becomes proportionally smaller, and appears as the clitoris, the two lateral masses becoming the labia majora. *In the male* a groove on the under surface unites at its borders to form the urethra, while the scrotum is formed from the folds of skin at the side. This differentiated condition may persist in adult life, and has been mistaken for hermaphrodism.

PARTURITION.

By **parturition** is meant the expulsion of the fœtus at a viable age from the mother. The average time for the full development of the fœtus is given at two hundred and seventy-eight days. During this time (period of gestation) the fœtus depends absolutely for its existence upon the mother. After parturition the child aërates its blood, ingests food, and purifies its body of wastes for itself. 5

Method of expulsion of fœtus: The fœtus is expelled in part by the contraction of the uterine muscles, and in part by the pressure exerted by the abdominal walls. The uterine contractions are the first to appear, and it is not until the fœtus enters the vagina that the abdominal muscles are brought into play.

Causes of uterine contractions: As to this no satisfactory answer has been given. Why the uterus should contain the growing embryo for months, and then be suddenly thrown into action to expel it, cannot be explained.

Nature of parturition: It is a reflex action depending upon a centre in the lumbar spinal cord. Whence the stimuli are derived which excite the reflex is unknown, but probably from the organ itself.

Character of uterine contractions: They are rhythmical in character, and may be compared to the contractions of the heart-muscle. Each "pain" begins feebly, gradually intensifies until it reaches a maximum, and then gradually declines until it entirely dies away, to be succeeded by another similar contraction and pause. This rhythmical action continues until the uterine contents are expelled, and then the organ enters into a condition of tonic contraction.

After parturition, by a process of involution lasting for a few weeks, the uterus returns to its normal unimpregnated state.

APPENDIX.

TABLE OF THE DEVELOPMENT OF AN EMBRYO.

(Modified from Gray's *Anatomy.*)

1st Week.—Ovum in Fallopian tube. Segmentation of vitellus.

2d Week.—Ovum in uterine decidua. Chorion. Formation of blastoderm and division of mesoderm. Heart and medullary groove. Amnion and umbilical vesicle formed. Allantois.

3d Week.—Head and tail flexures. Closure of medullary canal, and formation of primary cerebral vesicles and ocular and auditory vesicles. Branchial arches. Wolffian bodies. Limbs.

4th Week.—Limbs increased. Anal opening. Interventricular septum begins. Ant. spinal nerve-roots. Olfactory fossæ. Lungs. Pleuræ.

5th Week.—Allantois vascular. Trace of feet and hands. Müller's duct and genital gland.

6th Week.—Umbilical vesicle disused. Branchial clefts close. Post-spinal nerve-roots. Membranes of the nervous centres. Bladder. Kidneys. Tongue. Larynx.

7th Week.—Muscles perceptible. Many centres of ossification appear.

8th Week.—Joints appear in extremities; fingers and toes separate. Crystalline lens. Salivary glands. Spleen. Interventricular septum complete. Sympathetic nerves.

9th Week.—Distinction between ovary and testicle. Genital furrow. Pericardium.

3d Month.—Formation of placenta. External genitals separate from anus. Eyelids, hairs, and nails. Duct of Wolffian body joins testicle.

4th Month.—Middle-ear bones. Tympanum and labyrinth. Scrotum and prepuce.

5th Month.—Germs of teeth. Hair- and sweat-glands. Brunner's glands. Uterus and vagina distinctly separate.

6th Month.—Papillæ of skin. Sebaceous glands. Peyer's patches. Free border of nails.

7th Month.—Cerebral convolutions. Pupillary membrane disappears.

8th Month.—Descent of testis.

9th Month.—Opening of eyelids. Ossification of cochlea.

CHEMICAL TESTS USED COMMONLY IN PHYSIOLOGICAL ANALYSIS.

For Proteids:

Nitric Acid coagulates all except peptones.

Heat.—All are coagulated by boiling, except peptones.

Xanthoproteic Reaction.—A solution boiled with strong nitric acid becomes yellow: the color is deepened by the addition of ammonia.

Biuret Reaction.—With a trace of copper sulphate and an excess of potassium or sodium hydrate they give a purple reaction.

Millon's Reaction.—With a solution of metallic mercury in strong nitric acid (Millon's reagent) they give a white or pinkish reaction, and the color becomes more pink on boiling.

FOR STARCH:

Iodine Reaction.—Add to a solution of starch a small quantity of tincture of iodine, and a blue reaction results. The color disappears on heating and returns on cooling.

Glycogen.—Same test gives reddish reaction, port-wine color, which disappears on heating and returns on cooling.

FOR SUGAR (GLUCOSE):

Moore's Test.—Boil solution of sugar with an excess of potassium hydrate, brown color-reaction.

Trommer's Test.—Add to solution a sufficient amount of potassium hydrate to render it quite strongly alkaline. Then add a solution of copper sulphate, drop by drop, until a distinct blue tinge is visible. Heat, and the presence of sugar is shown by the appearance of red, yellow, or orange color-reaction.

Fehling's Test Solution.—An alkaline copper solution by which a quantitative test may be made. The solution is somewhat unstable, and is for this reason to be tested by boiling before using. The strength of the solution is such that 1 cubic cm. (15 minims) will be exactly decolorized by $\frac{1}{200}$th of a gramme (.075 grain) of glucose. This test is very delicate, and is quite commonly used for urinary examinations to detect glycosuria.

The Fermentation Test.—If a small quantity of yeast be added to a sugar solution, the fungus of the yeast (saccharomyces) will cause the sugar to be decomposed into carbonic acid and alcohol. If the process be continued until the sugar is entirely broken up, the amount of carbonic acid evolved indicates the proportion of sugar present.

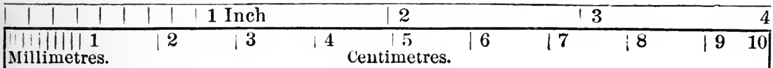
FOR BILE-SALTS:

Pettenkofer's Test.—Upon the addition of sulphuric acid to a solution of bile-salts in water there is a precipitation of the salts, which are redissolved by a further addition of the acid. If a drop of a solution of cane-sugar be added, a deep cherry color is developed.

FOR BILE-PIGMENTS:

Gmelin's Test.—Add a small quantity of nitroso-nitric acid to a solution of the bile-pigments, and a play of colors result, beginning with green and changing to blue, violet, red, and yellow. This is seen best on a white background; therefore a plate is often used for this test.

METRIC SYSTEM.



The area of the figure within the heavy lines is that of a square decimetre. A cube one of whose sides is this area is a cubic decimetre or *litre.* A litre of water at the temperature of 4° C. weighs a *kilogramme.*

A litre is 1.76 *pint;* a pint is 0.568 of a litre.

The smaller figures in dotted lines represent the areas of a square centimetre and of a squre inch.

A cubic centimetre of water at 4° C. weighs a *gramme.*

Square Inch.

Square Centi-metre.

Metre = $39\frac{2}{5}$ inches.
Centimetre = $\frac{2}{5}$ inch.
Millimetre = $\frac{1}{25}$ inch.
Micromillimetre = $\frac{1}{25000}$ inch.

Gramme = $15\frac{1}{2}$ grains.
Centigramme = $\frac{3}{20}$ grain.
Milligramme = $\frac{3}{200}$ grain.
Kilogramme = 2.2 pounds.

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